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The cod and the cod fishery at Faroe

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INTRODUCTION

THE Faroe region has for many years provided an important demersal fishery for vessels from England, Scotland and the Faroe Islands. The predominating fish species in the catches are cod, haddock and coalfish, of which cod is the most important, although in post-war years haddock landings have been increasing. During the period since the end of the second world war the amount of fishing has steadily increased and the abundance of cod has declined to a low level. The present study was undertaken to provide information on the basic biology of the Faroe cod and to assess from the available data and original research the effect of fishing on the stocks of cod.

THE GEOGRAPHICAL DISTRIBUTION OF THE FISHERY

THE demersal fishery in Faroese waters takes place mainly within two well defined areas which will here be referred to as the Faroe Plateau and Faroe Bank. The Faroe Plateau comprises the banks surrounding the Faroe Islands out to a depth of about 200 metres. Faroe Bank, situated to the south-west of the Islands, is separated from the Plateau by a deep-water channel with a maximum depth of about 1 000 m.

The area available to fishing on the Plateau is reduced by restrictions on fishing within territorial waters. In April 1959 the Danish government extended the Faroese exclusive fishing limits from three miles to twelve miles, but agreement was reached for British vessels to fish to within six miles of the coast with the exception of certain areas at certain times of year. Notice has since been given by the Danish government of exclusion of British vessels from within the twelve-mile limit, to take effect from March 1964. Faroe Bank is not affected by any such regulations.

The area of the Plateau available to fishing from the old six-mile exclusive fishing limit to the 200 m isobath is 15 600 sq km, and from the new twelve-mile limit 9 800 sq km. Faroe Bank is about 100 m deep at its shallowest and its area, bounded by the 200 m contour, is about 3 400 sq km.

To the south-west of Faroe Bank are two other banks – Bill Bailey's Bank and Lousy Bank – but these are of little importance and there is very little fishing on them.

PARTICIPATION IN THE FISHERY

ENGLISH, Scottish and Faroese vessels have accounted for approximately 90% of the landings of demersal fish from Faroese waters in recent years, and since the beginning of the century these three countries have shared the greater part of the Faroese fishery. The relative importance of the main demersal species in terms of weights landed during the periods 1924–38 and 1946–60 is shown in Table 1, together with the percentage distribution of the catch of each species between the main catching countries. The table is based on data published in the Bulletin Statistique, converted (where necessary) into round fresh weight. (Round fresh weight = gutted weight $\times 1{\cdot}2$.)

The relative importance of the Faroe fishery to the three nations concerned can be seen from the proportions by weight of demersal fish landed from the Faroe region, expressed as

Table 1. *Landings of cod, haddock and coalfish from the Faroe region, and the percentages of the total catch of each species landed by England, Scotland and Faroe*

Year	Total landings from Faroe (Metric tons, round fresh)†			Percentage of total landings of each species								
				Cod			Haddock			Coalfish		
	Cod	Haddock	Coalfish	England	Scotland	Faroe	England	Scotland	Faroe	England	Scotland	Faroe
1924	45 194	10 907	8 095	73	18	9	84	16	0	84	14	2
1925	38 292	8 954	7 667	67	14	17	84	16	0	88	11	1
1926	44 181	10 211	5 300	62	23	12	77	23	0	85	14	0
1927	45 168	11 296	6 521	60	24	15	80	20	0	85	15	0
1928	30 309	11 536	7 575	62	24	13	86	14	0	92	8	0
1929	26 501	9 015	7 543	68	21	7	89	11	0	93	7	0
1930	33 021	10 690	7 727	63	24	6	82	18	0	93	7	0
1931	45 418	13 711	8 737	71	23	3	80	20	0	92	8	0
1932	44 741	17 356	10 215	67	22	10	83	16	0	91	8	0
1933	37 721	12 636	12 160	68	24	6	82	18	0	93	7	0
1934	35 497	12 495	10 717	71	24	5	83	17	0	94	6	0
1935	32 120	14 844	10 962	72	22	5	79	21	0	96	4	0
1936	34 770	16 553	10 833	69	27	3	76	24	0	92	8	0
1937	26 643	15 462	6 426	59	30	11	74	25	1	95	5	0
1938	23 754	17 380	7 152	61	27	11	75	24	1	92	8	0
1946	30 483	17 030	5 325	52	32	16*	65	35	–‡	85	15	–‡
1947	30 990	15 750	8 758	55	29	16*	53	47	–	83	17	–
1948	20 170	12 083	3 569	35	41	24*	39	61	–	71	29	–
1949	28 134	11 315	6 114	42	40	18*	34	66	–	62	38	–
1950	35 975	13 776	5 366	44	42	14*	34	66	–	65	35	–
1951	35 394	14 409	8 698	45	41	14*	45	55	–	78	22	–
1952	33 515	14 271	6 851	37	40	23	53	47	1	83	17	0
1953	27 141	15 012	7 175	46	39	15	39	43	18	85	15	0
1954	36 206	15 403	6 212	44	39	14	38	44	17	89	11	0
1955	38 858	16 573	7 234	45	32	20	30	46	23	78	14	1
1956	27 574	17 515	10 884	30	38	29	33	43	24	43	11	0
1957	31 485	20 995	26 858	32	43	22	33	46	21	14	3	4
1958	27 897	23 871	12 978	35	38	23	31	40	29	53	11	3
1959	25 982	20 239	14 545	39	41	18	26	46	28	39	11	4
1960	39 220	25 727	11 845	35	42	22	27	43	30	54	18	6

† Round fresh weight = gutted weight × 1·2. * Estimated; no data available. ‡ No data 1946–51; assumed nil.

percentages of the total national demersal landings by England, Scotland and the Faroe Islands which were as follows:

	1959	1960	1961	1962
England	4%	6%	2%	2%
Scotland	13%	19%	16%	18%
Faroe	20%	22%	22%	14%

In recent years a large proportion of the Faroese catch of cod from Faroe has been landed fresh at United Kingdom ports and the actual quantities are estimated as follows: 1959: 1 578 tons, gutted weight (equivalent to approximately 40% of the total Faroese catch of cod from Faroe waters); 1960: 3 766 tons (60%); 1961: 5 299 tons (70%); 1962: 4 795 tons (75%).

The English fishery, which is almost entirely a trawl fishery, takes place both on the Faroe Plateau and Faroe Bank, and the division of catch and fishing effort between these two areas in recent years is shown in Table 2. The majority of English vessels fishing at Faroe are based at Grimsby.

Table 2. *Catch of cod (metric tons, round fresh weight), fishing effort (hours fishing) and catch per unit effort (metric tons per 100 hours fishing) by English trawlers fishing at Faroe Plateau and Faroe Bank during the period 1946–62*

	Faroe Plateau			Faroe Bank		
Year	Catch	Effort	C.P.U.E.	Catch	Effort	C.P.U.E.
1946	13 015	44 953	29·0	1 313	5 941	22·1
1947	11 529	52 160	22·1	3 065	16 210	18·9
1948	5 424	36 008	15·1	1 165	8 636	13·5
1949	10 797	48 909	22·1	872	5 900	14·8
1950	13 904	65 595	21·2	1 911	12 089	15·8
1951	12 410	69 149	17·9	3 547	28 202	12·6
1952	9 650	61 069	15·8	2 617	24 590	10·6
1953	10 695	58 232	18·4	1 572	11 269	13·9
1954	13 461	56 349	23·9	2 494	16 657	15·0
1955	13 675	48 769	28·0	3 423	17 534	19·5
1956	5 070	28 938	17·5	3 269	22 266	14·7
1957	8 088	44 742	18·1	1 956	15 975	12·2
1958	6 460	49 347	13·1	3 371	27 635	12·2
1959	7 454	55 199	13·5	2 534	20 174	12·6
1960	8 205	57 460	14·3	5 220	43 981	11·9
1961	3 004	38 672	7·8	816	10 913	7·5
1962	3 804	36 967	10·3	1 404	17 677	7·9

Nearly all the Scottish fishing effort is concentrated on Faroe Plateau, with very little fishing on the Bank. This, too, is predominantly a trawl fishery, but there is also some long-lining. Most of the Scottish fleet fishing at Faroe is based at Aberdeen.

Faroese participation in the fishery has become increasingly important in the last few years. The Faroese fishery is entirely a line fishery, both long-lines and hand-lines being used. There have been no Faroese trawlers operating in Faroese waters. Fishing takes place both on Faroe Plateau and on Faroe Bank but no data are available from which to distinguish landings from Plateau and Bank. A rough estimate of the ratio of catches from Plateau and Bank has been obtained from the results of tagging experiments during the winter of 1962–3, which was the only period when tagged fish were at liberty in both areas at the same time. From the numbers of tags recovered per unit weight of cod in English and Scottish landings, and the number of tags recovered from the Faroese fishery, it is estimated that landings of cod from Faroe Bank constituted one seventh of the total Faroese cod catch. However, due to the sparseness of data no great reliance should be placed on this estimate.

The English and Scottish fisheries at Faroe continue throughout the whole year. On Faroe Plateau the catch of cod, fishing effort and catch per unit effort for the English fleet usually reach maximum values in March-April when the mature fish are aggregated for spawning. Fishing effort falls off in late spring and rises to a second peak in the summer, but catch per effort is lower then than in spring.

Scottish fishing effort reaches a maximum during the summer months, with a lesser peak in spring. Peak landings of cod are made in the spring and summer months and, as for the English fleet, the Scottish catch of cod per unit effort reaches a maximum during the spring spawning season.

The Faroese fishery for cod takes place during the winter months, the season extending from November till May.

COD STOCKS AND MIGRATIONS

TAGGING experiments on cod at Faroe conducted by Danish workers during the periods 1909–13 and 1923–37 showed that there was very little interchange of cod between the Plateau and Bank stocks (Strubberg 1916, 1933; Tåning, 1940). In these experiments a total of 6 467 cod were tagged on Faroe Plateau and 585 on Faroe Bank, the total recaptures numbering 2 225 and 87 respectively. From these recaptures there were records of only three fish migrating from Faroe Plateau to Faroe Bank and only two fish making the migration in the reverse direction.

More recently, in 1959–63, English tagging experiments at Faroe have confirmed the separate nature of the Plateau and Bank stocks. Fish were tagged in both areas and total recaptures to date are given in Table 3. It is probable that these results indicate a greater degree of interchange between Plateau and Bank than in fact occurs, due to incorrect reporting of position of recapture. The reliability of recapture data decreases the further

Table 3. *Distribution of recaptures of cod tagged in Danish and English experiments. The total numbers of reported migrations between Plateau and Bank are given, and of these the numbers reported by crew members of the catching vessels are shown in brackets* (*see text*). *Danish results from Strubberg* (1916, 1933) *and Tåning* (1940)

	Number of fish tagged		Number recaptured		
			Faroe Plateau	Faroe Bank	Other areas
Danish-tagged cod 1909–13, 1923–37	Plateau	6 467	2 220	3	2
	Bank	585	2	85	–
English-tagged cod 1959–63	Plateau	3 026	805	18 (6)	–
	Bank	1 134	12 (6)	197	–

along the distributing chain the tag is found. In Table 3 the figures in brackets represent the number of the total recaptures reported by skippers or crew members of the catching vessels, and for these the recapture data are probably reliable. For all experiments the returns from fishermen constitute about 50% of all tags recovered. The remaining tags were found in later stages of handling after the fish had been landed, when it is often difficult to ascertain exactly the position of recapture.

Thus the evidence so far available points to there being two separate, self-contained cod stocks supporting the fishery at Faroe. The distribution of these two stocks corresponds to the two main fishing areas and they will here be referred to as the Faroe Plateau stock and the Faroe Bank stock.

Further evidence for the independent status of the Plateau and Bank stocks is provided by the growth data, which show that the Bank fish have a more rapid growth rate than the fish on the Plateau (see section on growth).

One problem raised by the independent nature of the two stocks is how the Bank stock maintains itself. Fraser (1958) stated that although the planktonic fish eggs and larvae of Faroe Plateau were retained over the banks by eddies, it seemed likely that eggs and larvae resulting from spawnings on Faroe Bank would be carried away from the Bank by the easterly or south-easterly flow of the surface water currents over the Bank. Fraser goes on to say that recruitment to Faroe Bank can be assumed to result from adult migrations from Faroe Plateau. Results of tagging experiments show no evidence of Plateau fish recruiting to Faroe Bank, although tagging has been restricted to fish larger than 30 cm in length. In his racial investigations of the Atlantic cod Schmidt (1930) made vertebral counts of fish from both Plateau and Bank. Mean numbers of vertebrae for the two areas were 52·28 and 51·77, the difference between the means being significant ($P < 0{\cdot}001$). Such a difference in vertebral counts would not be expected if Bank cod were recruited from the Plateau. It seems much more likely that the Bank fish are a self-maintained population. Unfortunately, there has been no detailed study of the flow of surface waters over Faroe Bank, but a recent plankton survey by the author (unpublished) in May 1963, over the northern part of the Bank and in the deep-water channel to the east and south-east of it, showed no evidence of cod larvae being carried away from the Bank out over deep water. Cod larvae were present over the Bank (an average of thirty-nine larvae per haul for five hauls) but very rare over the deep water (averaging less than one per haul for five hauls).

It also appears that there is very little interchange of cod between Faroe and other regions. From the Danish tagging experiments only three fish were reported as being recaptured away from Faroe, two in the Northern North Sea and one from Bear Island. None of the recaptures from our own tagging experiments was reliably reported as caught away from the Faroe region.

There is evidence of a small amount of immigration to Faroe from other regions. Tåning (1934, 1943) records the recapture at Faroe of two cod tagged at Iceland and one tagged at West Greenland. Holden (1960) discussed the evidence from otoliths of immigration to Faroe of slower-growing cod probably of Norway coast origin. More recent otolith samples have also contained occasional otoliths differing from the typical Faroe type, but these are few in number and constitute less than 1% in the samples from Faroe. Some of these otoliths are of typical Icelandic pattern and are possibly indicative of a small amount of immigration from Iceland.

GROWTH

VERY little information on the growth rate of cod at Faroe has been published. Tåning (1943) gives length ranges for fish of various ages from Faroe Plateau and Faroe Bank, but does not give mean lengths. The present data are based on ages determined from otoliths collected over the period 1959–62. Otoliths provide the most satisfactory means of age determination of cod, and growth data from tagged fish support the validity of age determinations from otoliths. All age determinations are related to a birthday which is taken to be 1 January.

There is a distinct difference in the rates of growth of fish from Faroe Plateau and Faroe Bank, that of the Bank fish being the more rapid. Growth curves for cod from the two areas are illustrated in Figure 1, where the points plotted are observed values, and the lines drawn represent the best fitting growth curves calculated from the von Bertalanffy (1938) growth equation, when in the usual notation:

$$l_t = L_\infty (1-e^{-K(t-t_0)}).$$

The parameters of the growth equation, based on mean lengths of age-groups II–IX, have been determined for each stock and are as follows:

Faroe Plateau: $L_\infty = 115{\cdot}3$ cm, $K = 0{\cdot}19$, $t_0 = -0{\cdot}42$ years
Faroe Bank: $L_\infty = 110{\cdot}3$ cm, $K = 0{\cdot}40$, $t_0 = 0{\cdot}73$ years.

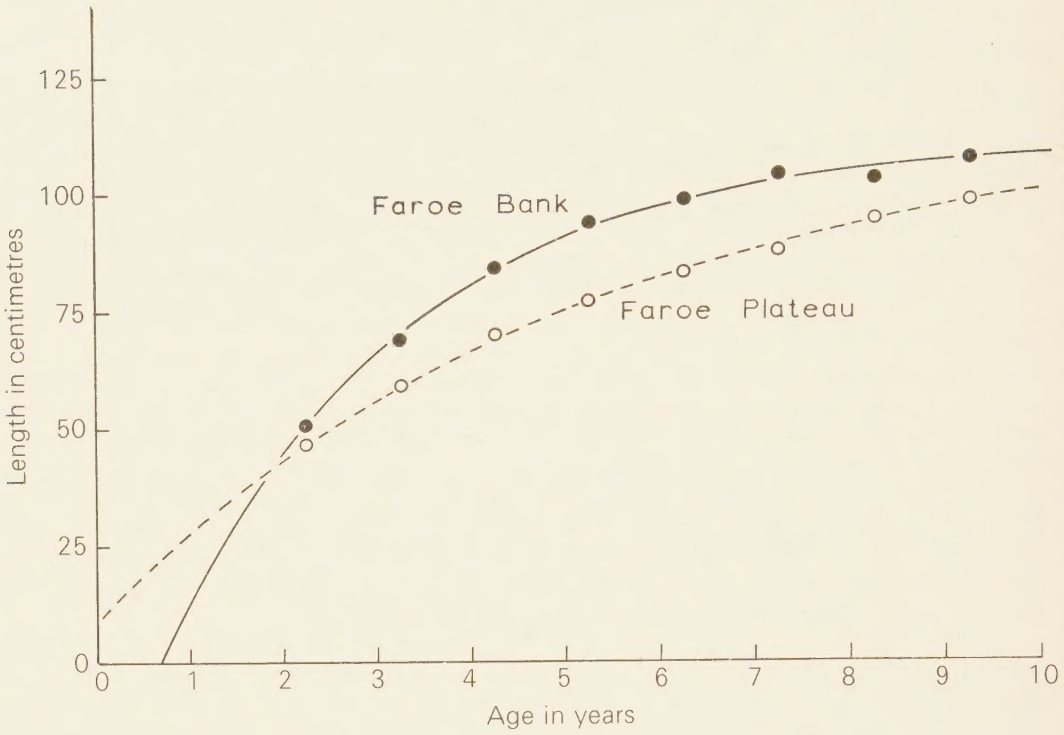

Fig. 1. *Growth curves of cod from Faroe Plateau and Faroe Bank. Points shown are observed mean lengths for each age-group during the period* 1959–62. *The fitted curves shown were calculated using the von Bertalanffy growth equation.*

THE EFFECTS OF FISHING

(*a*) CATCH, EFFORT AND CATCH PER UNIT EFFORT

ANNUAL catch and fishing effort statistics are available over a long period of years for the English and Scottish fisheries at Faroe. For the Faroese fishery, catch statistics only are available from the Bulletin Statistique.

Total landings of cod from the Faroe region are given in Table 4, and are plotted graphically in Figure 2 (a). Fishing effort data are available as hours fished by English and Scottish trawlers. Average gross tonnage of trawlers is known for the post-war years and has been estimated for the pre-war period. Gulland (1956) has shown that the fishing power of trawlers is approximately proportional to gross tonnage and that the best measure of fishing effort for the English demersal fisheries is the 'ton-hour'. This unit of effort is adopted by the present author. Gulland also showed that the fishing power of motor trawlers was, ton for ton, greater than that of steam trawlers. Motor trawlers commenced fishing at Faroe soon after the end of the second world war and have become increasingly important, until now they have almost completely replaced steam trawlers. However, as records of hours fished by steam trawlers are available over a longer period of years, fishing effort and catch per unit effort have been expressed in terms of steam trawler ton-hours. An index of stock abundance is given by the catch per unit fishing effort. Two estimates of this are available from the separate catch and effort records of the English and Scottish fleets fishing at Faroe. A comparison of mean annual catch per unit effort by English and Scottish steam trawlers (Figure 3) shows that the fishing power is effectively the same for English and Scottish

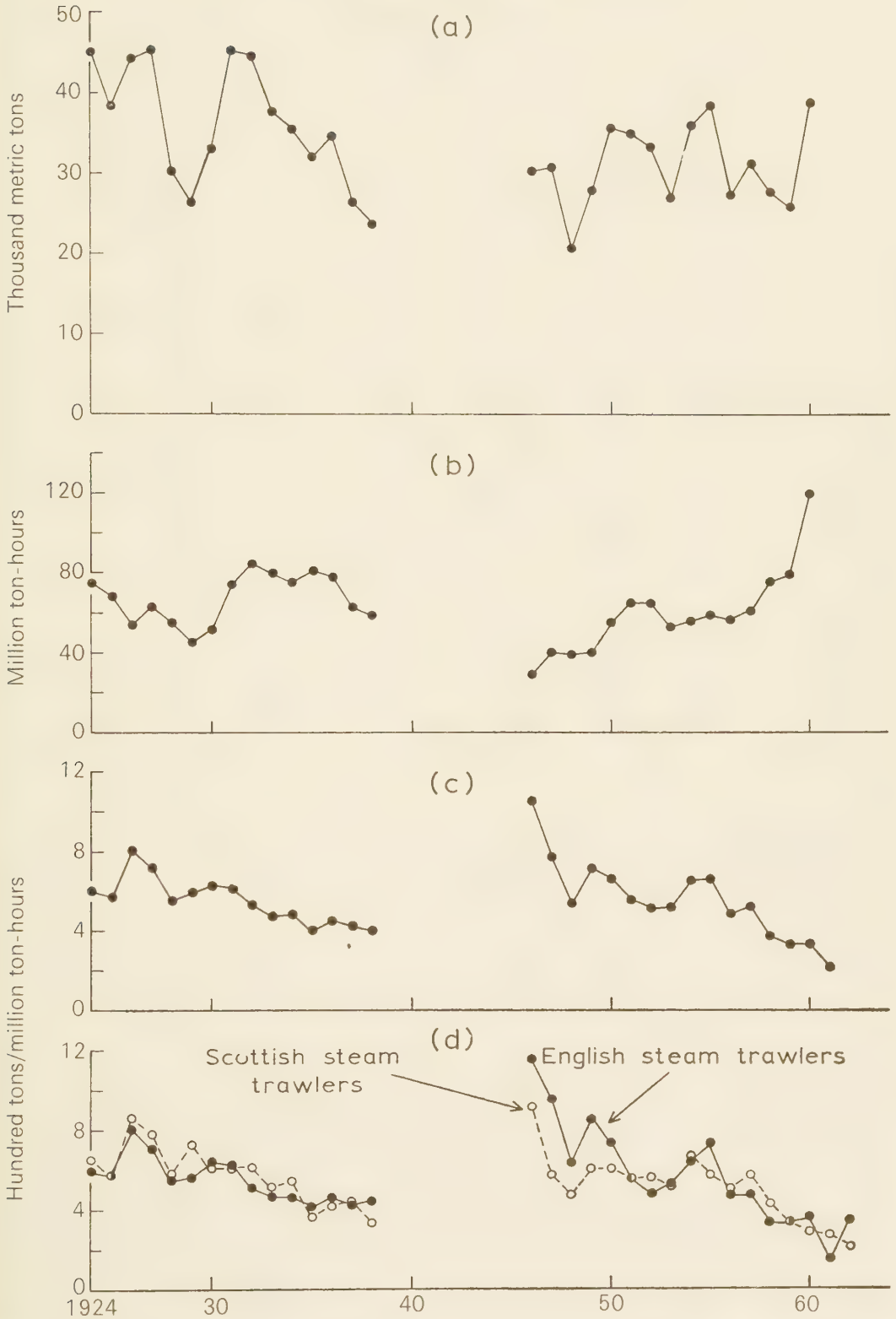

Fig. 2. *Catch of cod, fishing effort and catch per unit effort from the Faroe region.* (a) *Total landings by all nations* (*metric tons, round fresh weight*). (b) *Estimated total fishing effort* (*British steam-trawler ton-hour units*). (c) *Catch per unit fishing effort* (*metric tons per million steam-trawler ton-hours*). (d) *Catch per unit fishing effort of English and Scottish steam trawlers separately* (*metric tons per million ton-hours*).

Table 4. *Annual landings of cod from the Faroe region, 1924–38 and 1946–60*

Year	Landings of cod (metric tons, round fresh)				
	England	Scotland	Faroe	Other nations	Total
1924	33 000	8 252	3 942		45 194
1925	25 825	5 324	6 507	636	38 292
1926	27 590	10 366	5 331	894	44 181
1927	26 894	10 724	6 782	768	45 168
1928	18 894	7 295	4 078	42	30 309
1929	18 140	5 599	1 783	979	26 501
1930	20 794	7 843	2 146	2 238	33 021
1931	32 209	10 538	1 482	1 189	45 418
1932	29 765	10 057	4 308	611	44 741
1933	25 729	9 200	2 153	639	37 721
1934	25 183	8 500	1 807	7	35 497
1935	23 230	7 195	1 621	74	32 120
1936	23 897	9 382	1 187	304	34 770
1937	15 678	7 862	2 954	149	26 643
1938	14 585	6 457	2 641	71	23 754
1946	15 819	9 664	*5 000		30 483
1947	17 075	8 886	*5 000	29	30 990
1948	7 318	8 392	*5 000		20 710
1949	11 829	11 305	*5 000		28 134
1950	15 786	15 167	*5 000	22	35 975
1951	15 977	14 417	*5 000		35 394
1952	12 365	13 283	7 692	175	33 515
1953	12 469	10 535	4 137		27 141
1954	16 017	14 238	5 190	761	36 206
1955	17 660	12 380	7 902	916	38 858
1956	8 337	10 610	7 938	689	27 574
1957	10 067	13 413	6 920	1 085	31 485
1958	9 828	10 523	6 535	1 011	27 897
1959	10 087	10 522	4 676	697	25 982
1960	13 746	16 300	8 723	451	39 220

* No data; estimated.

vessels of equivalent tonnage, and therefore English and Scottish catch and effort data have been combined for the purposes of this paper (Table 5). British catch per unit effort is given in Table 6 and is shown in Figure 2 (c). For comparison the catches per unit effort for English and Scottish steam trawlers are shown separately in Figure 2 (d). Total fishing effort for the Faroe region (Table 6, Figure 2 (b)) has been estimated by dividing the total international landings by the British catch per unit effort, and is therefore in the form of the number of British steam trawler ton-hours which would be required to obtain a catch equal to the total international landings from the region.

In post-war years the total annual landings from the Faroe region have fluctuated about the 30 000 tons level but there has been no distinct trend in landings. Fishing effort, on the other hand, has increased steadily since the end of the war. Corresponding to the upward trend in fishing effort is a steadily decreasing catch per unit effort, suggesting that at the present level of fishing effort the stock abundance is very sensitive to changes in the amount of fishing. In Figure 4 the stock density (catch per unit effort) in a given year has been related to the mean fishing effort during that year and the preceding year (Gulland, 1961). Two years approximates to the average lifespan in the fishery, after recruitment to the exploited phase. It is apparent that there is a decline in stock abundance with increasing fishing effort. A straight line does not necessarily give the best fit for the points plotted (Gulland, 1961): a curvilinear relationship is more probable, and the line shown gives a better fit to the points for the post-war years. At recent levels of effort, indicated by arrows, it would appear that at the present level of fishing there has been a reduction in stock density to at least a fifth of the unfished state.

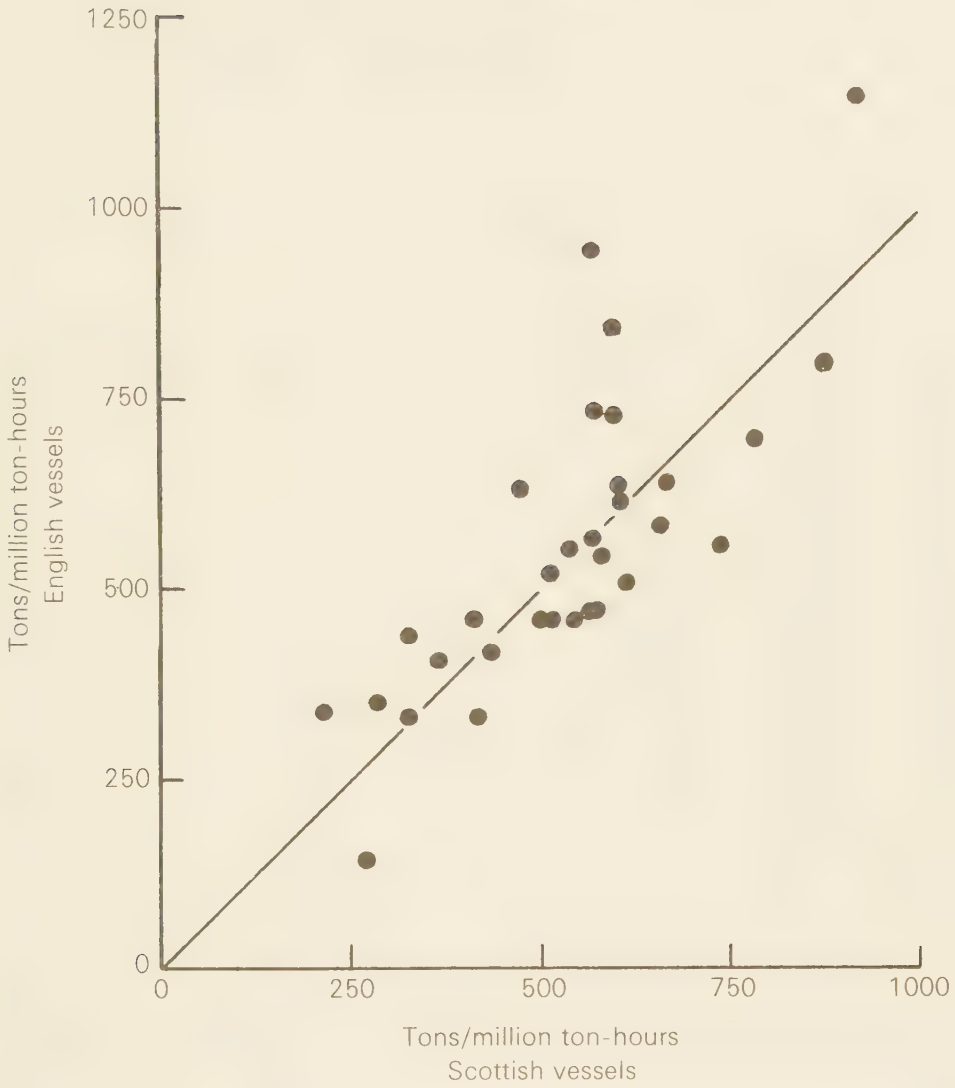

Fig. 3. *Mean annual catch of cod per unit fishing effort of English steam trawlers against Scottish steam trawlers for the years* 1924–38 *and* 1946–62. *The line drawn is of equality of English and Scottish catch per unit effort.*

The foregoing considerations have been based on catch and effort statistics for the Faroe region as a whole. It has been pointed out, however, that there are two separate stocks supporting the fishery and it is more appropriate to consider separately the effect of fishing on each of these stocks. Separate catch and effort statistics are available for the two stocks only for the English fishery in the post-war years and for the Scottish fishery from 1955 onwards. Data for the British fisheries are in the form of catch and effort records for each ICES statistical rectangle, and the division by statistical rectangles adopted for the two stocks is shown in Figure 5.

At present no information is available on how the total Faroese catch is divided between Plateau and Bank, and it is therefore not possible to estimate the total fishing effort for the two areas separately with any degree of reliability. However, examination of the English catch per unit effort data for the two areas plotted separately (Table 2, Figure 6) shows a

Table 5. *Fishing effort by English and Scottish steam trawlers fishing at Faroe 1924–38, 1946–62*

Year	English steam trawlers			Scottish steam trawlers			Total British steam-trawler effort (ton-hours $\times 10^{-3}$)
	Hours fishing	Average gross tonnage	Ton-hours $\times 10^{-3}$	Hours fishing	Average gross tonnage	Ton-hours $\times 10^{-3}$	
1924	224 531	250	56 128	45 461	240	10 911	67 039
1925	181 901	250	45 475	30 737	240	7 377	52 852
1926	137 854	250	34 464	39 322	240	9 437	43 901
1927	153 744	250	38 436	38 153	240	9 157	47 593
1928	138 849	250	34 712	35 664	240	8 559	43 271
1929	129 969	250	32 492	28 376	240	6 810	39 302
1930	130 287	250	32 572	46 226	240	11 094	43 666
1931	209 380	250	52 345	64 206	240	15 409	67 754
1932	234 203	250	58 551	57 735	240	13 856	72 407
1933	223 300	250	55 825	64 312	240	15 435	71 260
1934	219 057	250	54 764	53 313	240	12 795	67 559
1935	229 034	250	57 258	58 931	240	14 143	71 401
1936	208 199	250	52 050	75 667	240	18 160	70 210
1937	150 268	250	37 567	54 783	240	13 148	50 715
1938	133 131	250	33 283	58 934	240	14 144	47 427
1946	51 740	266	13 763	42 640	240	10 234	23 997
1947	68 617	263	18 046	62 880	240	15 091	33 137
1948	44 774	258	11 552	68 441	240	16 426	27 978
1949	54 863	255	13 990	68 640	240	16 474	30 464
1950	77 724	279	21 685	95 612	240	22 947	44 632
1951	97 187	295	28 670	102 834	243	24 989	53 659
1952	86 091	304	26 172	88 366	251	22 180	48 352
1953	68 973	340	23 451	76 020	254	19 309	42 760
1954	72 219	338	24 410	77 255	255	19 700	44 110
1955	64 804	342	22 163	74 589	256	19 095	41 258
1956	46 009	361	16 609	67 429	254	17 127	33 736
1957	49 464	357	17 659	62 812	258	16 205	33 864
1958	42 478	386	16 397	44 246	264	11 681	28 078
1959	30 447	406	12 361	29 995	284	8 519	20 880
1960	32 443	453	14 697	27 649	296	8 184	22 881
1961	8 184	447	3 658	14 329	298	4 270	7 928
1962	1 946	464	902	16 576	295	4 890	5 792

similar downwards trend in the post-war period for both the Plateau and the Bank, suggesting a similar decline in abundance of fish in both stocks.

(*b*) ESTIMATION OF TOTAL MORTALITY RATES

Estimates of total mortality rates of cod at Faroe have been obtained from the age compositions of English and Scottish landings. Age determinations were commenced in 1959, and for any given year a single age/length key has been used to convert the length compositions of both English and Scottish landings to age compositions. Histograms of age compositions in terms of numbers and weight per 100 hours' fishing are shown in Figure 7 for Plateau and Bank separately. The Scottish landings from Faroe Plateau* in recent years have included a higher proportion of small fish than the English landings (Figure 8). Full recruitment to the Scottish fishery is probably effected when the fish are little more than two years old. Full recruitment of the English fishery occurs at a slightly older age. This may be due to differences in the geographical distribution of the two fleets, or to a selectivity effect due to different rigging of the trawl and differences in the codend mesh sizes used. At the recent

* Total Scottish landings from the Faroe region. Although referred to in this paper as coming from Faroe Plateau, Scottish landings include a small proportion of fish (about 2%) from Faroe Bank.

Table 6. *Landings of cod from Faroe (metric tons, round fresh) and catch per unit effort (tons per million ton-hours) by British steam trawlers, with total landings by all countries and equivalent international effort (thousands of British steam-trawler ton-hours)*

Year	British steam trawlers		Total international catch	Equivalent international effort in British units
	Total catch	Catch per unit effort		
1924	40 141	599	45 194	75 449
1925	29 989	567	38 292	67 534
1926	35 743	814	44 181	54 276
1927	34 054	716	45 168	63 084
1928	23 841	551	30 309	55 007
1929	23 140	589	26 501	44 993
1930	27 460	629	33 021	52 498
1931	41 524	613	45 418	74 091
1932	38 208	528	44 741	84 737
1933	33 648	472	37 721	79 917
1934	32 137	476	35 497	74 574
1935	28 344	397	32 120	80 907
1936	31 379	447	34 770	77 785
1937	21 410	422	26 643	63 135
1938	19 175	404	23 754	58 797
1946	25 166	1 049	30 483	29 059
1947	25 601	773	30 990	40 091
1948	15 013	537	20 710	38 566
1949	21 636	710	28 134	39 625
1950	29 438	660	35 975	54 508
1951	29 279	546	35 394	64 824
1952	24 812	513	33 515	65 331
1953	22 069	516	27 147	52 610
1954	28 729	651	36 206	55 616
1955	27 108	657	38 858	59 145
1956	16 215	481	27 574	57 326
1957	17 568	519	31 485	60 665
1958	10 281	366	27 897	76 221
1959	6 855	328	25 982	79 213
1960	7 470	326	39 220	120 307
1961	1 661	210	26 951	128 338

levels of fishing intensity the maximum contribution of a year-class, in terms of weight, is made at an age of three years to the Scottish fishery and at an age of three to four years to the English fishery. On Faroe Bank, recruitment to the English fishery occurs at a slightly earlier age than on the Plateau; the greatest contribution to annual yield in weight is made at an age of two to three years.

During the years for which data are available there has been no very marked fluctuation in strength of year-classes. The 1954 year-class was the most successful in recent years in both Plateau and Bank stocks. The 1955 year-class was poor, particularly on the Bank.

Annual values of the total instantaneous mortality coefficient, Z, have been calculated from English and Scottish landings for Plateau and Bank stocks (Table 7). Values of Z for the Plateau stock for different pairs of age-groups are rather variable, but the overall means obtained from English and Scottish landings show reasonably good agreement, with values of 1·04 and 1·09. Estimates of total mortality rates for the Bank stock can be obtained only from English data, which give a mean value of 1·27.

COD TAGGING EXPERIMENTS

(*a*) INTRODUCTION

ENGLISH cod tagging experiments at Faroe were commenced in 1959 and have continued up to the time of writing. Individual experiments, with numbers released and recaptured,

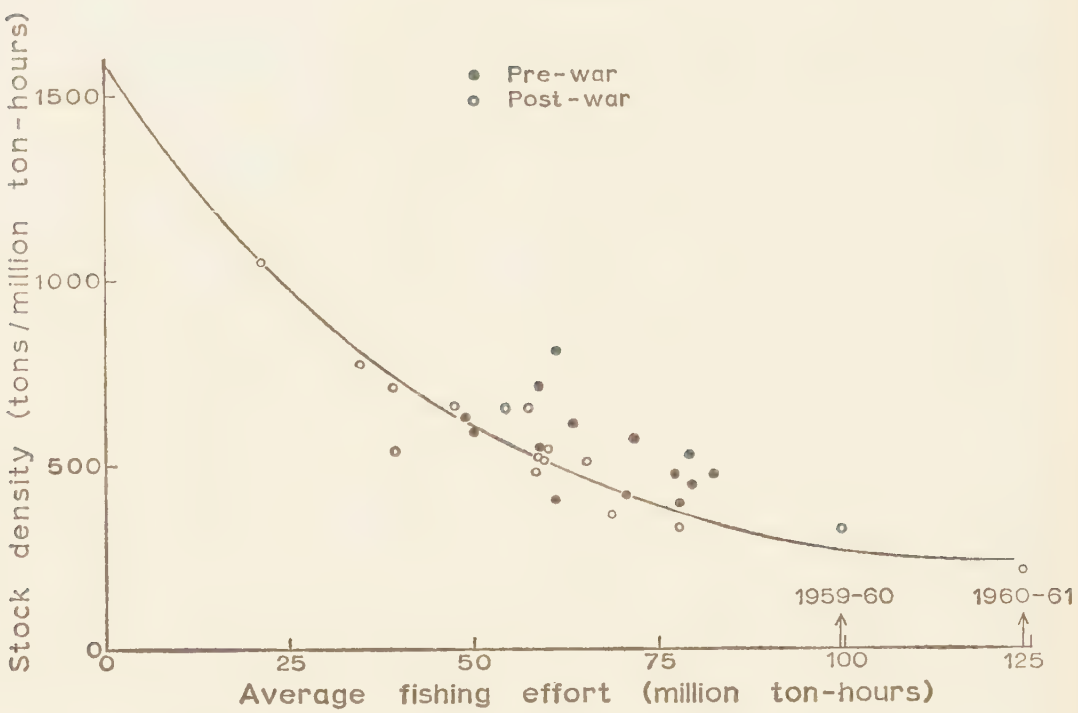

Fig. 4. *Faroe cod,* 1925–38 *and* 1946–60. *Stock density in each year plotted against mean fishing intensity during that year and the preceding year. The line represents a possible curvilinear relationship for the points for post-war years. The arrows indicate the levels of fishing intensity in* 1959–60 *and* 1960–61.

are listed in Table 8. The majority of recaptures are made during the two years after tagging and very few recaptures are reported in the third or subsequent years. All fish for tagging were trawl-caught. The standard tag used was the Lowestoft plastic flag (Williams, 1963) attached by a braided nylon loop through the dorsal musculature between first and second dorsal fins or in front of the first dorsal fin. In the experiments of July and December 1961, Petersen disc tags were used on some fish instead of flag tags, and were attached by stainless steel wires through the dorsal musculature between first and second dorsal fins.

The results of the tagging experiments in relation to the separation of fish stocks have been discussed above. The results are here further analysed to provide information on mortality rates.

(*b*) COMPARISON OF PLASTIC FLAG AND PETERSEN DISC TAGS

Both plastic flag and Petersen disc tags were used in the 1961 July and December releases. The number of fish tagged and recaptured in the December liberation was small and the results have not been compared in any detail; a total of one hundred fish were tagged, fifty-two with flag tags and forty-eight with Petersen discs. Subsequent recaptures numbered fifteen flag tags and three Petersen discs. In the July experiment a total of 1 200 cod were tagged on Faroe Plateau, using flag tags and Petersen discs alternately in the ratio 2:1 (801 flag tags and 399 Petersen discs). Reported recaptures have been in the same ratio (233 flag tags and 118 Petersen discs). Rates of recapture for the two tag types do not differ to any extent (Figure 9), and no distinction will therefore be made between plastic flags and Petersen disc tags in the subsequent analyses.

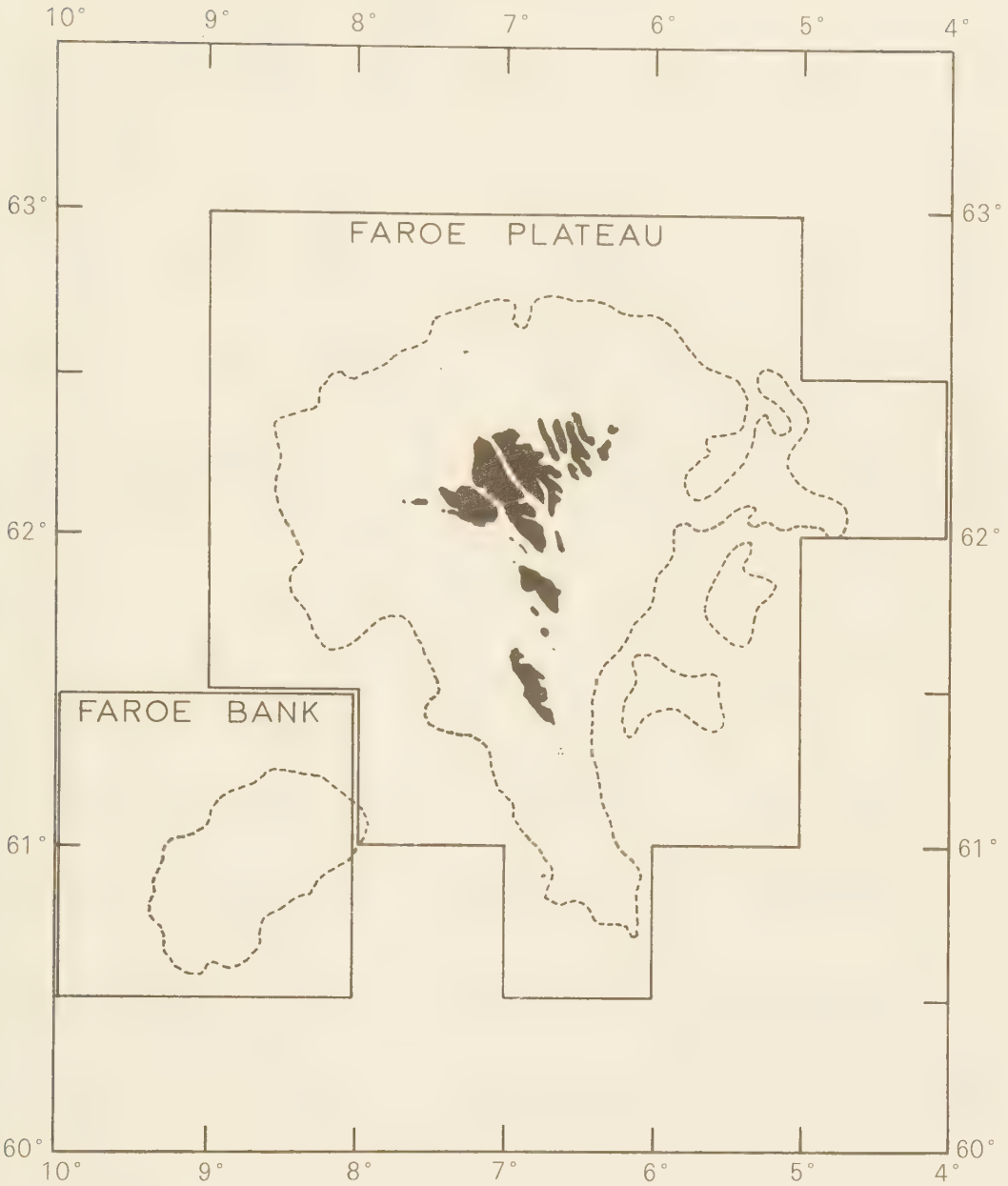

Fig. 5. *Division by statistical rectangles of the Faroe region into Faroe Plateau and Faroe Bank.* (*Each rectangle represents half a degree of latitude and one degree of longitude. The broken line is the* 100-*fathom contour.*)

(*c*) RELATIONSHIP BETWEEN LENGTH AT LIBERATION AND SUBSEQUENT RECAPTURE

The histograms in Figure 10 show the length composition of all tagged fish liberated in the four major tagging experiments, and the length compositions at liberation of the recaptures. Also indicated is the percentage of recaptures in each 5-cm length group. From the May 1959 liberation there was a clear trend towards an increasing proportion of recaptures with

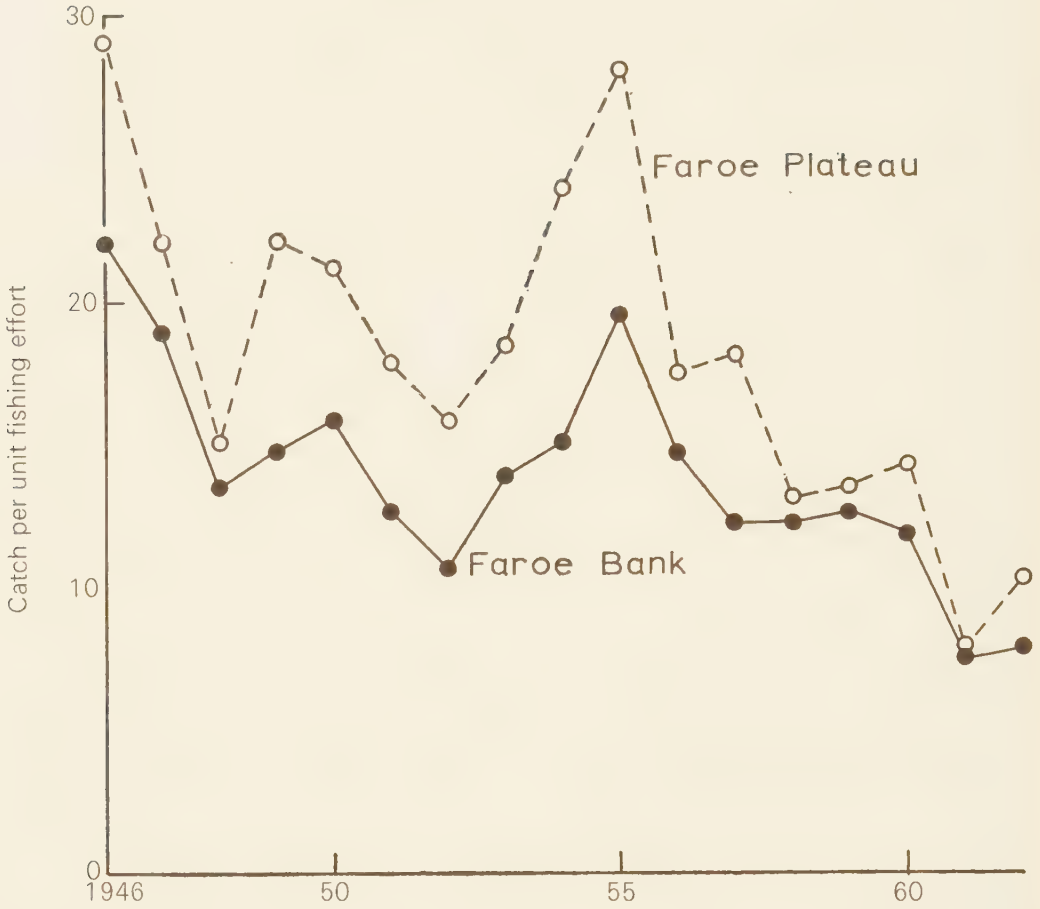

Fig. 6. *Catch of cod per unit fishing effort* (*metric tons per* 100 *hours' fishing*) *by English trawlers fishing at Faroe Plateau and Faroe Bank.*

increasing length at liberation. A similar trend may be discerned for the July 1959 liberation but is not so marked for the July 1961 releases. The relationship between length at liberation and proportion recaptured appears to remain approximately constant throughout the length range in the June 1962 experiment on Faroe Bank. It is interesting to note that a similar relationship between length at liberation and percentage recaptured was reported by McCracken (1963), for trawl-caught cod off Nova Scotia but not for line-caught fish.

The numbers of fish in the present experiments are rather too small for differences in the rate of recapture to be discerned for each length group. The two largest liberations have been examined, however, by comparing the recapture rates of small fish (less than 60 cm at liberation) with those of large fish (60 cm or larger at liberation). Natural logarithms of the numbers recaptured in successive periods of time have been plotted for the two size groups in Figure 11. Apparent total mortality rates given by the slopes of the lines show no significant difference between small and large fish in the May 1959 experiment, but for the July 1961 experiment the apparent total mortality rate for the larger fish was significantly greater ($P < 0{\cdot}01$) than that for small fish. This could suggest that the intensity of fishing on the larger fish is greater than on the smaller fish. This could be accounted for by the Faroese long-line fishery exploiting mainly large fish and by the intensive British trawl fishery on the mature fish during the spring spawning season. Estimates of total mortality coefficients from age composition data (Table 7), however, show no evidence of increasing mortality with increasing age.

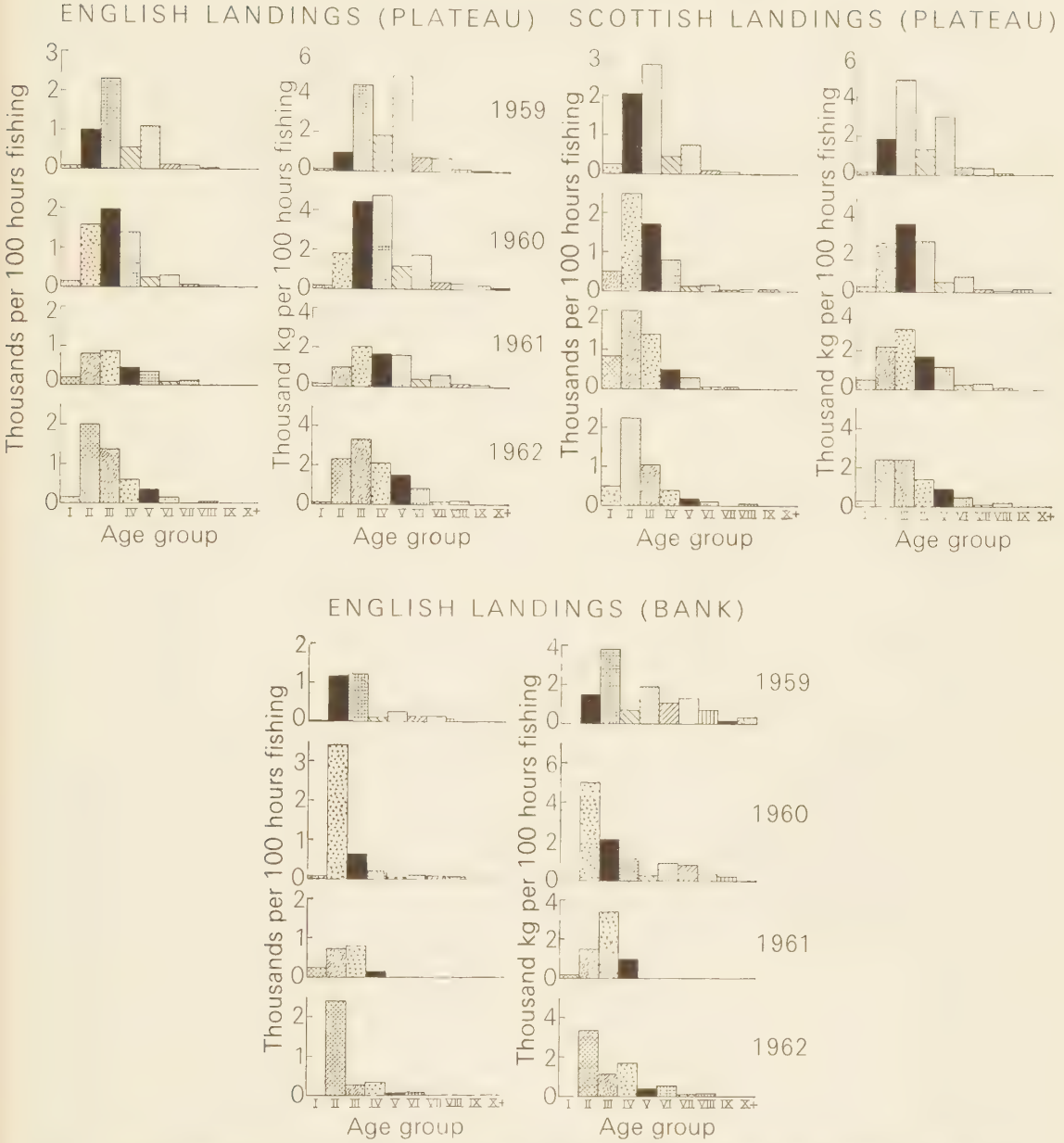

Fig. 7. *Age compositions of cod per* 100 *hours' fishing, by numbers and weight, of English landings from Faroe Plateau and Faroe Bank, and of Scottish landings from Faroe Plateau,* 1959–62.

(*d*) ESTIMATION OF THE TOTAL MORTALITY COEFFICIENT

The total instantaneous mortality coefficient, Z′, can be estimated from the ratio of numbers of tagged fish recaptured in successive periods of time, when

$$Z'T = \log_e \frac{n_v}{n_{(v+1)}} \qquad (1)$$

where n_v and $n_{(v+1)}$ are numbers of tagged fish recaptured in successive periods of time of

Fig. 8. *Mean percentage length composition, 1959 62, of English and Scottish landings of cod from Faroe Plateau.*

Table 7. *Annual values of the instantaneous total mortality coefficient, Z, calculated for Faroe Plateau and Faroe Bank cod stocks. (A) from English landings, and (B) from Scottish landings*

A. English landings

Age Group	FAROE PLATEAU 1959–60	1960–61	1961–62	Mean 1959–62	FAROE BANK 1959–60	1960–61	1961–62	Mean 1959–62
II–III					0·64	1·45	0·92	1·00
III–IV					1·88	1·44	0·97	1·43
IV–V	0·75	1·39	0·16	0·77	1·47	1·39	1·24	1·37
V–VI	1·34	1·24	0·80	1·13				
VI–VII	0·94	1·22	1·40	1·19				
VII–VIII	1·03	1·06	1·09	1·06				
Mean Z	1·02	1·23	0·86	1·04	1·33	1·43	1·04	1·27

B. Scottish landings

Age Group	FAROE PLATEAU 1959–60	1960–61	1961–62	Mean 1959–62
IV–V	1·28	1·09	0·93	1·10
V–VI	1·70	0·96	1·06	1·24
VI–VII	1·11	1·09	1·37	1·19
VII–VIII	0·78	0·94	0·81	0·84
Mean Z	1·22	1·02	1·04	1·09

Table 8. *Numbers of cod tagged and recaptured in each liberation on Faroe Plateau and Faroe Bank*

Liberation date	Area	Number of fish tagged	Total recaptured to December 1963	Percentage recaptured to December 1963
1959 March	Faroe Plateau	20	8	40
	Faroe Bank	30	9	30
1959 May	Faroe Plateau	696	211	30
	Faroe Bank	22	7	32
1959 July	Faroe Plateau	488	77	16
	Faroe Bank	9	1	11
1959 October	Faroe Plateau	91	18	20
1960 May	Faroe Plateau	155	60	39
	Faroe Bank	68	16	24
1960 September	Faroe Plateau	97	32	33
	Faroe Bank	10	1	10
1961 July	Faroe Plateau	1 200	365	30
	Faroe Bank	18	6	33
1961 December	Faroe Plateau	100	18	18
1962 June	Faroe Plateau	173	47	27
	Faroe Bank	749	163	22
1963 May	Faroe Plateau	6	0	0
	Faroe Bank	228	24	11

duration T. (Dashed symbols, Z' and F', are used to distinguish mortality coefficients calculated from tagging experiments from those calculated from age composition data.) Thus an estimate of Z' can be obtained from a plot of natural logarithms of numbers recaptured in successive periods of time, the slope of the regression giving an estimate of $Z'T$. Such plots are given for three liberations on Faroe Plateau (Figure 12, a–c) and one liberation on Faroe Bank (Figure 12, d). Estimated annual values of the instantaneous coefficient of total mortality, Z', were as follows:

Faroe Plateau liberations, May 1959 $Z' = 1{\cdot}65$
July 1959 $= 1{\cdot}39$
July 1961 $= 1{\cdot}82$

Mean value of $Z' = 1{\cdot}62$

Faroe Bank liberation, June 1962 $Z' = 2{\cdot}08$.

(*e*) ESTIMATION OF THE FISHING MORTALITY COEFFICIENT OF THE FAROE PLATEAU STOCK

In order to make the fullest use of the available data, the method of analysis adopted is based on that of Paloheimo (1958), modified so that several liberations could be treated as a continuous tagging experiment. Using this modification recapture data from single liberations, which on their own might be inadequate for analysis, have been combined in a way such that the seasonal pattern of recapture is unaltered.

Taking $Z' = F' + X$

where $F' =$ instantaneous coefficient of fishing mortality

and $X =$ instantaneous coefficient of mortality due to other causes including natural mortality,

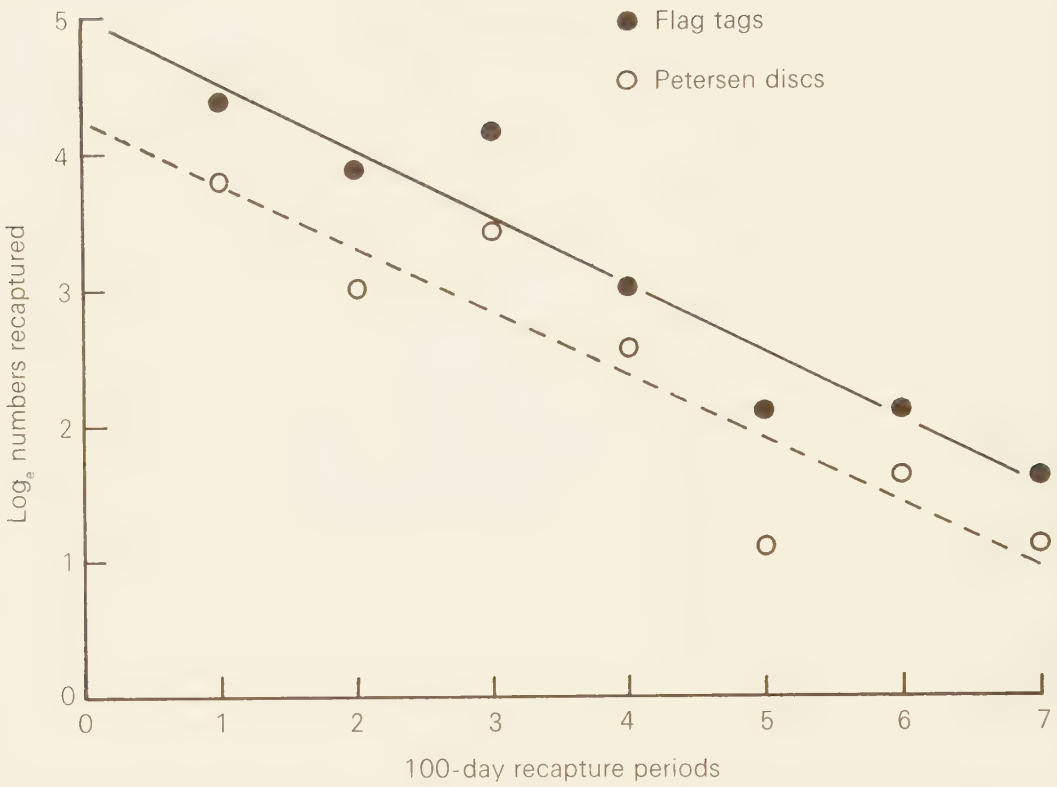

Fig. 9. *Logarithms of numbers of flag tags and Petersen discs recaptured in successive* 100*-day periods from the July* 1961 *liberation.*

Paloheimo assumed arbitrary values of X and calculated the corresponding values of F′ from the equation

$$F'_v = \frac{n_v}{N_v} \div 1 - \left(\frac{(n_v/N_v) + X_v}{2} \right) \tag{2}$$

where F'_v = quarterly instantaneous coefficient of fishing mortality during time interval v

X_v = assumed quarterly instantaneous coefficient of mortality due to other causes during time interval v

N_v = number of tagged fish at liberty at beginning of time interval v

n_v = number of tagged fish recaptured during time interval v.

Numbers of tagged fish at liberty at the beginning of each time interval are given by

$$N_{(v+1)} = N_v e^{-(F'_v + X_v)}. \tag{3}$$

Equation (2) is an approximation which can be used only if the chosen intervals of time are of short duration. Here three-month periods are used, the first period in each year corresponding to the months February, March and April.

Using equations (2) and (3) alternately values of F'_v have been calculated for each quarter year period for assumed arbitrary values of X_v of 0·25, 0·30 and 0·35. The data from the individual liberations of May, July and October 1959, May and October 1960, and July 1961 have been treated as a single continuous tagging experiment. It has been assumed that a period of three months was adequate for the tagged fish to mix reasonably uniformly with the untagged population, and only fish recaptured after an initial period of

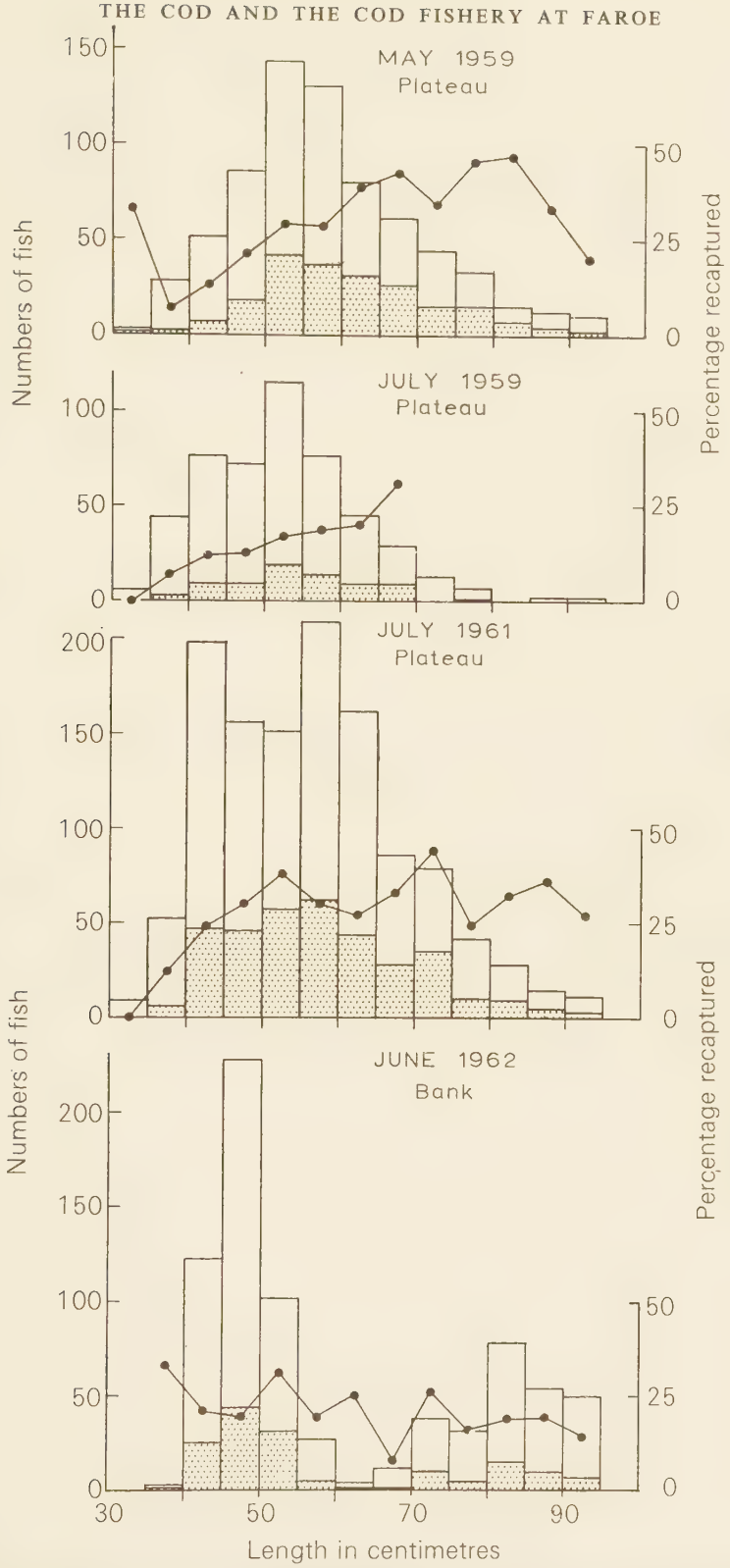

Fig. 10. *Length compositions of cod tagged in four experiments (open histograms) and the length compositions at release of fish subsequently recaptured (stippled histograms). The percentage of recaptures in each 5-cm length group is also shown.*

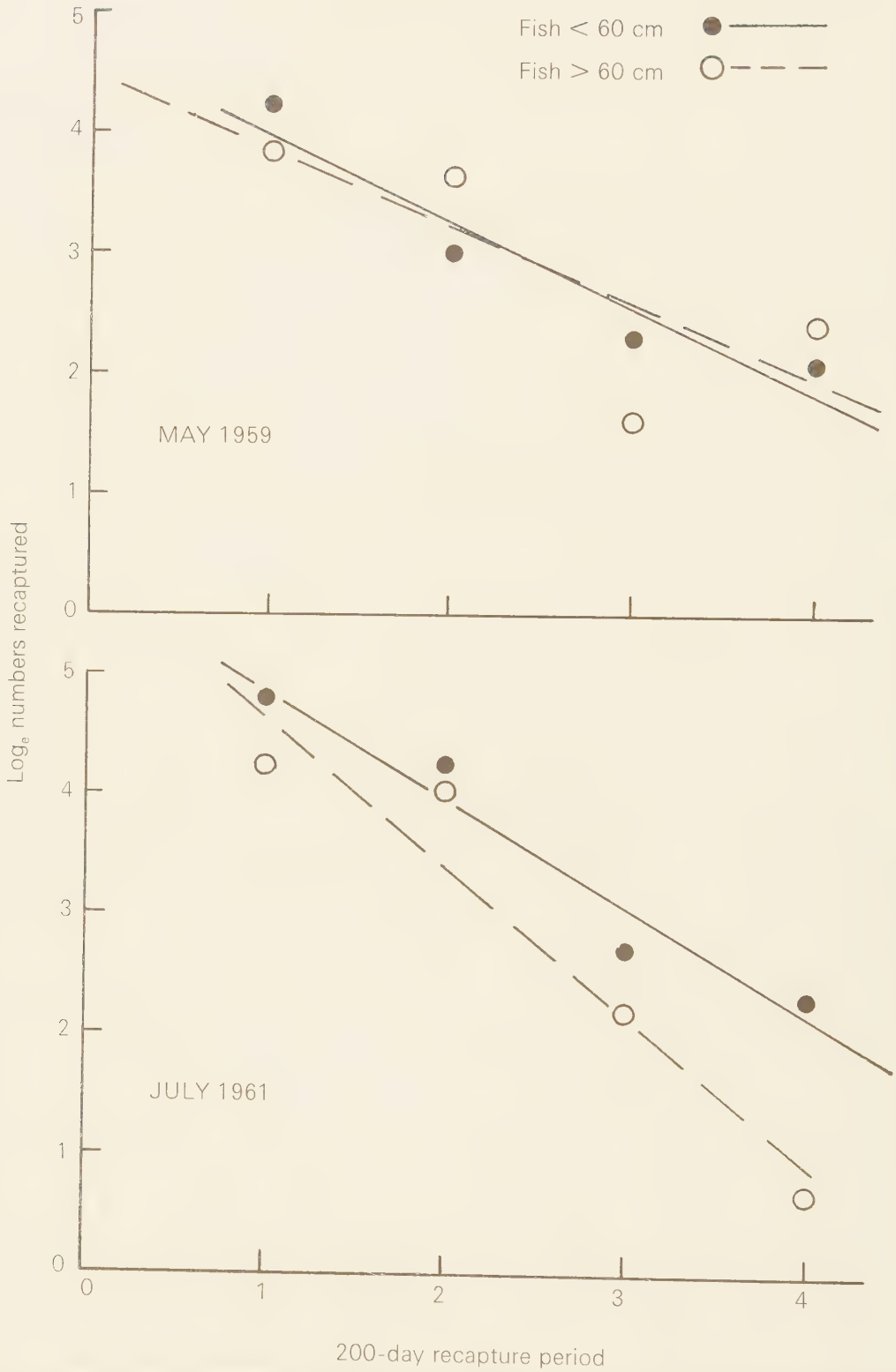

Fig. 11. *Logarithms of numbers of large (* > *60 cm at liberation) and small (* < *60 cm at liberation) tagged cod recaptured in successive 200-day periods from liberations in May* 1959 *and July* 1961.

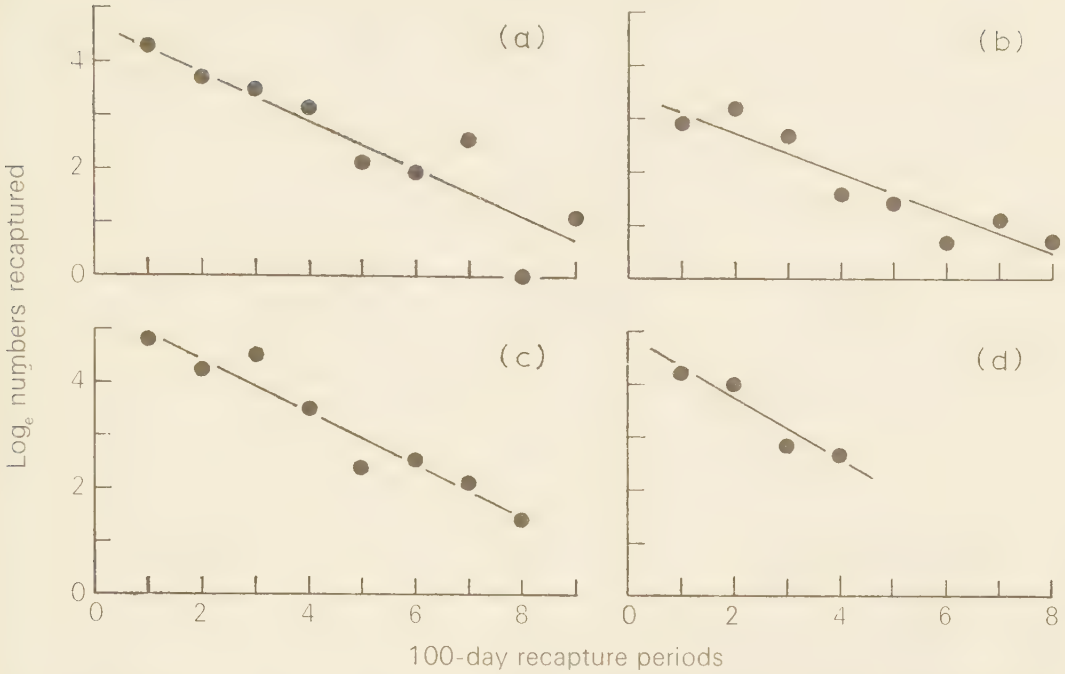

Fig. 12. *Logarithms of numbers of tagged cod recaptured in successive* 100*-day recapture periods, from four tagging experiments.* (a) *May* 1959, *Faroe Plateau.* (b) *July* 1959, *Faroe Plateau.* (c) *July* 1961, *Faroe Plateau.* (d) *July* 1962, *Faroe Bank.*

approximately three months after liberation have been included in the calculations of fishing mortalities.

Thus for the liberation of May 1959, the number of tagged fish released, N_0, was 696 (Worksheet, Table 9). During the initial period of time, t 0·19 years, the number of tagged fish recaptured, n_1, was 67. The numbers of tagged fish remaining at liberty at the end of the initial period, which are the numbers, $N_{v(a)}$, at liberty at the beginning of the first quarterly period (a), have been calculated using equations (2) and (3) giving values of $N_{v(a)}$ 515, 494 and 474 for the three assumed values of the 'other loss' coefficient X. Each of the quarterly periods is identified as (a) (p), and the numbers of recaptures, n_v, in each period are listed for each individual liberation and the sum from all liberations is given in the right-hand column of the first part of the worksheet.

The three values of $N_{v(a)} = 515$, 494 and 474 are the numbers of tagged fish from the May 1959 liberation remaining at liberty at the beginning of the first quarterly period (a), and are carried over into the second part of the table. Values of $F'_{v(a)}$ are calculated for the period (a) from $N_{v(a)}$ and $n_{v(a)}$. The numbers of tagged fish remaining at liberty at the end of the period were 372, 338 and 307. To these are added the numbers of fish remaining at liberty at the end of the initial period after the July 1959 liberation, giving totals of tagged fish of 721, 667 and 617 at liberty at the beginning of the second quarter (b).

Continuing in this manner quarterly values of F'_v have been calculated for each of the three assumed values of X_v over a total period of four years. Mean annual values of F′ of 0·35, 0·45 and 0·65 were obtained, corresponding to assumed annual values of X of 1·0, 1·2 and 1·4. The relationship between X and F′ X is plotted graphically in Figure 13 (line a). If the value of Z F′ X is taken to be 1·62, as determined from tagging experiments, this gives a value of X = 1·18, and hence F′ = 1·62 − 1·18 = 0·44.

Estimates of mortality coefficients from tagging experiments give a value for Z′ of 1·62, which is larger than the estimate obtained from age composition data (Z 1·07). The separation of Z′ into a fishing mortality coefficient and an 'other loss' coefficient gave a large value for X (= 1·18) and a small value for F′ (= 0·44). It is obvious that the value of X thus obtained is too large to be due to natural mortality alone.

Table 9. *Worksheet used to calculate fishing mortality coefficients for the Faroe Plateau cod stock from tagging experiments*

	INDIVIDUAL LIBERATIONS ON FAROE PLATEAU																		
	May 1959			July 1959			October 1959			May 1960			October 1960			July 1961			
N_0 =	696			488			91			155			97			1 200			
n_t =	67			18			7			34			10			132			
t =	0·19			0·29			0·29			0·23			0·33			0·31			
X =	1·0	1·2	1·4	1·0	1·2	1·4	1·0	1·2	1·4	1·0	1·2	1·4	1·0	1·2	1·4	1·0	1·2	1·4	
N_v =	515	494	474	349	329	310	62	58	55	93	88	83	61	57	53	766	716	668	
	n_v v = 0·25 years																		Σn_v
1959 Aug./Sept./Oct. (a)	32																		32
Nov./Dec./Jan. (b)	29			23															52
1960 Feb./Mar./Apr. (c)	34			14			6												54
May/June/July (d)	13			5			1												19
Aug./Sept./Oct. (e)	8			4						8									20
Nov./Dec./Jan. (f)	9			1			1			5									16
1961 Feb./Mar./Apr. (g)	10			3			1			8			8						30
May/June/July (h)	1			2						1			5						9
Aug./Sept./Oct. (i)				1						1			2						4
Nov./Dec./Jan. (j)										2			1			62			65
1962 Feb./Mar./Apr. (k)	1			1			1						1			85			89
May/June/July (l)													1			33			34
Aug./Sept./Oct. (m)													1			9			10
Nov./Dec./Jan. (n)																9			9
1963 Feb./Mar./Apr. (o)										1			1			10			12
May/June/July (p)																6			6

X = / X_v =	1·0 / 0·25	1·2 / 0·30	1·4 / 0·35			1·0 / 0·25	1·2 / 0·30	1·4 / 0·35
v = 0·25 years	N_v				n_v	F'_v		
1959 Aug./Sept./Oct. (a)	515	494	474		32	0·074	0·079	0·085
	372	338	307					
	349	329	310	(July 1959)				
Nov./Dec./Jan. (b)	721	667	617		52	0·086	0·096	0·108
	515	449	390					
	62	58	55	(Oct. 1959)				
1960 Feb./Mar./Apr. (c)	577	507	445		54	0·113	0·134	0·159
May/June/July (d)	401	328	268		19	0·056	0·071	0·090
	295	226	173					
	93	88	83	(May 1960)				
Aug./Sept./Oct. (e)	388	314	256		20	0·061	0·078	0·099
Nov./Dec./Jan. (f)	284	215	163		16	0·066	0·092	0·127
	207	145	101					
	61	57	53	(Oct. 1960)				
1961 Feb./Mar./Apr. (g)	268	202	154		30	0·137	0·191	0·268
May/June/July (h)	182	124	83		9	0·058	0·089	0·141
Aug./Sept./Oct. (i)	134	84	51		4	0·035	0·058	0·100
	101	59	33					
	766	716	668	(July 1961)				
Nov./Dec./Jan. (j)	867	775	701		65	0·090	0·104	0·119
1962 Feb./Mar./Apr. (k)	617	517	439		89	0·180	0·225	0·280
May/June/July (l)	401	306	234		34	0·102	0·140	0·193
Aug./Sept./Oct. (m)	282	197	136		10	0·041	0·062	0·093
Nov./Dec./Jan. (n)	211	137	87		9	0·050	0·080	0·134
1963 Feb./Mar./Apr. (o)	156	94	54		12	0·092	0·162	0·311
May/June/July (p)	111	59	28		6	0·064	0·127	0·299
						$\Sigma F'_v = 1·305$	1·788	2·606
						$\bar{F}' = 0·326$	0·447	0·652
						$X + \bar{F}' = 1·33$	1·65	2·05

N_0	Number of tagged fish liberated.
n_t	Number recaptured in initial period of duration t.
N_v	Calculated number of tagged fish remaining at liberty at beginning of each time period v (0·25 years).
n_v	Number recaptured during each quarterly period, v.
X and X_v	Assumed annual and quarterly values of instantaneous 'other loss' coefficient.
F'_v	Calculated quarterly value of instantaneous fishing mortality coefficient.

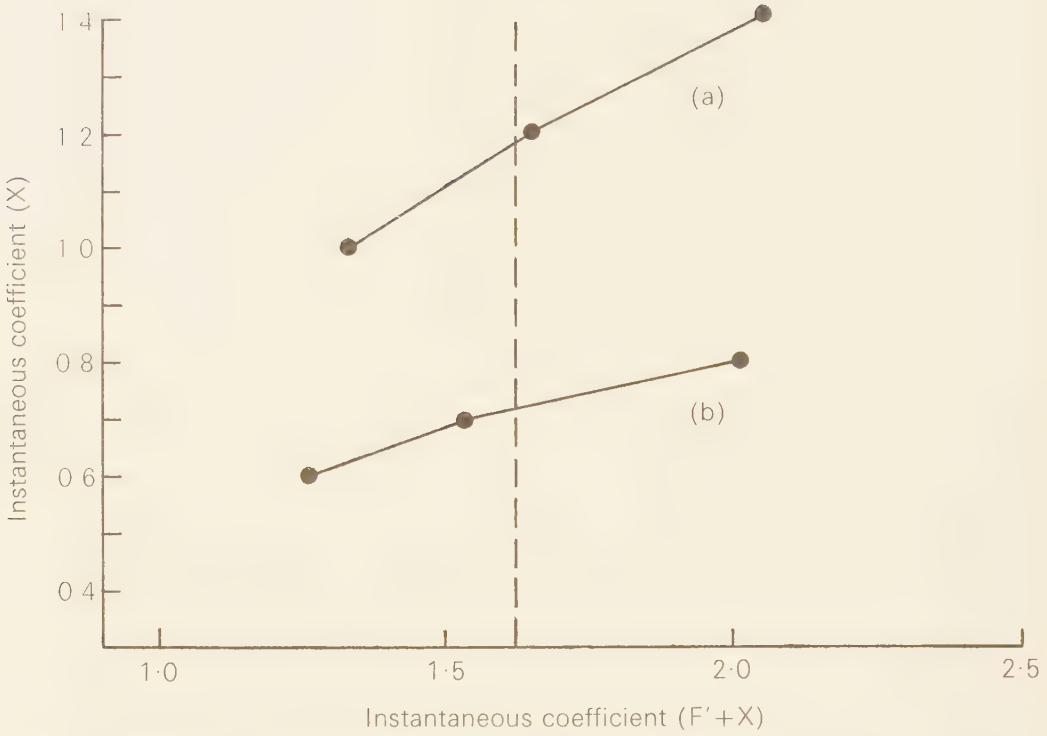

Fig. 13. *Relationships between assumed values of the instantaneous coefficient of 'other loss', X, and calculated values of the instantaneous coefficient of total mortality (F' + X):* (a) *Uncorrected (Worksheet, Table* 9). (b) *Corrected for tagging mortality and incomplete reporting of recaptured tags (Worksheet, Table* 10).

Errors affecting estimates of mortality rates from tagging experiments can be considered to be of two main types. Type A errors (Ricker, 1948) affect estimates of fishing mortality but not of total mortality, and include tagging mortality, i.e. death of a proportion of tagged fish soon after release, and incomplete reporting of recaptured tags. Type B errors affect estimates of total mortality but not fishing mortality. Such errors include steady shedding of tags, emigration of tagged fish from the area under study, and extra mortality of the tagged fish not experienced by the untagged population.

An estimate of the magnitude of Type B errors is given by the difference of the values of total mortality coefficients as calculated from tagging experiments and from age composition data, i.e. $Z' - Z = 1{\cdot}62 - 1{\cdot}07 = 0{\cdot}55$ ($Z = 1{\cdot}07$ is the mean value of estimates calculated from English and Scottish data for the Plateau stock). Thus the value of the 'other loss' coefficient X can be reduced by 0·55 to give a value of $1{\cdot}18 - 0{\cdot}55 = 0{\cdot}63$.

It is known that there is some error due to Type A losses. Both tagging mortality and efficiency of tag reporting are difficult to estimate quantitatively, but reasonable values have been assumed and used to correct for Type A errors. Dickie (1963) showed that the initial survival of trawl-caught tagged cod in the Gulf of St. Lawrence was only 71% as high as that of handline-caught fish. My colleague, Mr. P. M. J. Woodhead, has informed me that in cod-tagging experiments when cod have been retained after tagging in tanks aboard the research vessel, survival of tagged fish was of the order of 60% to 70%. It is possible here that confining the fish in tanks has resulted in a somewhat increased mortality, but on the basis of these observations a value of 30% has been assumed for tagging mortality.

Little information is available concerning the efficiency of tag reporting. Investigations by Margetts (1963) into the efficiency of tag recovery from the English distant-water landings indicated that the proportion of tags not recovered probably exceeds 25%. No comparable data are available for the Scottish or Faroese fisheries. A comparison of ratios of tags

reported to the numbers of fish landed for English and Faroese vessels fishing on Faroe Plateau is not possible as Faroese landings from the Plateau are not known. An English-Scottish comparison indicates little difference between the ratio of tags reported to numbers of fish landed in the period January 1960 to December 1961.

Country	Tags reported	Estimated number of fish landed	Tags reported per million fish landed
Scotland	146	14 081 000	10·4
England	39	4 409 000	8·9

This suggests that there is little difference in efficiency of reporting of tags from English and Scottish landings.

Assuming that Type A errors are caused by a combination of tagging mortality and failure to report recaptured tags, quarterly values of the fishing mortality coefficient, F', have been recalculated incorporating a correction for Type A errors. In this calculation tagging mortality has been assumed to be 30% and accordingly the initial number of fish tagged has been reduced by this amount. The proportion of recaptured tags actually reported is taken to be 70%, and the number of tags reported has been increased by a factor of 1·43. The calculation is reproduced in Table 10. The mean annual values of F' obtained were 0·66, 0·83 and 1·2, corresponding to assumed annual values of X of 0·6, 0·7 and 0·8. The relationship between X and $F' + X$ is plotted in Figure 13 (line b). Taking $F' + X = 1{\cdot}62$ then X = 0·72 and F' = 0·90. If the corrections for errors affecting the tagging experiments have been of the right order of magnitude, F' should now be equivalent to F, the true coefficient of fishing mortality. The only remaining cause of 'other loss' mortality should be mortality due to natural causes. As determined from age composition data $F + M = 1{\cdot}07$, and therefore the coefficient of natural mortality $M = 1{\cdot}07 - 0{\cdot}90 = 0{\cdot}17$. This value of M = 0·17 is of the order of magnitude that might be expected and compares well with the value of the natural mortality coefficient reported for a similar exploited cod stock at Iceland, where Jónsson (1960) found the value of M to be between 0·1 and 0·2 for the mature population.

To summarize the estimation of mortality rates as determined from tagging experiments for the Plateau stock, best estimates of the annual coefficients of natural and fishing mortality of $M = 0{\cdot}17$ and $F = 0{\cdot}90$ have been obtained.

(*f*) COMPARISON WITH RESULTS OF EARLIER DANISH COD-TAGGING EXPERIMENTS

Earlier Danish cod-tagging experiments at Faroe have been described by Strubberg (1916, 1933) and Tåning (1940). Neither author made any attempt to calculate mortality rates. Total mortality rates can be estimated from Strubberg's data for the earlier experiments, in which the numbers of fish tagged and recaptured were sufficiently large. Treating all releases in a given year as a single experiment, annual values of the instantaneous total mortality coefficient, Z', have been calculated from regressions of logarithms of numbers recaptured in successive three-monthly periods of time. Estimates of Z' for the years 1909–13 and 1923 for Faroe Plateau liberations range in value from 1·60 to 2·20 with a mean of 1·90, compared with a mean value of 1·62 obtained above. However, these earlier Danish experiments are not directly comparable with the present experiments in that the fish tagged were predominantly of a small size and were released close to land. Subsequent recaptures were made mainly by Faroese fishermen (91% of total recaptures) with very few recaptures by English or Scottish vessels (Table 11). In the period from 1909 up to the beginning of the first world war the Faroese share of the total cod catch was about 35% and was greater than it has been in subsequent years. This on its own would not account for such a high proportion of

Table 10. *Worksheet used to calculate fishing mortality coefficients for the Faroe Plateau cod stock from tagging experiments. Corrected for Type A errors*

	INDIVIDUAL LIBERATIONS ON FAROE PLATEAU																		
	May 1959			July 1959			October 1959			May 1960			October 1960			July 1961			
N_0	487			342			64			109			68			840			
n_t	96			26			10			49			14			189			
t	0·19			0·29			0·29			0·23			0·33			0·31			
X	0·6	0·7	0·8	0·6	0·7	0·8	0·6	0·7	0·8	0·6	0·7	0·8	0·6	0·7	0·8	0·6	0·7	0·8	
N_v	344	337	329	263	256	248	45	43	42	50	49	47	43	41	40	526	507	488	
	n_v v = 0·25 years																		Σn_v
1959 Aug./Sept. Oct. (a)		46																	46
Nov./Dec./Jan. (b)		41			33														74
1960 Feb./Mar./Apr. (c)		49			20			8											77
May/June/July (d)		19			7			1											27
Aug./Sept./Oct. (e)		11			6						12								29
Nov./Dec./Jan. (f)		13			2			1			7								23
1961 Feb./Mar./Apr. (g)		14			4			2			11			12					43
May/June/July (h)		1			3						2			7					13
Aug./Sept./Oct. (i)					2						1			3					6
Nov./Dec./Jan. (j)											3			1			89		93
1962 Feb./Mar./Apr. (k)		2			2			1						1			121		127
May June July (l)														2			47		49
Aug./Sept./Oct. (m)														1			13		14
Nov./Dec./Jan. (n)																	13		13
1963 Feb./Mar./Apr. (o)											1			2			14		17
May/June/July (p)																	9		9

X =	0·6	0·7	0·8			0·6	0·7	0·8
X_v =	0·150	0·175	0·200			0·150	0·175	0·200
v = 0·25 years		N_v			n_v		F'_v	
1959 Aug./Sept./Oct. (a)	344	337	329		46	0·156	0·162	0·168
	253	241	228					
	263	256	248	(July 1959)				
Nov./Dec./Jan. (b)	516	497	476		74	0·168	0·178	0·189
	376	349	323					
	45	43	42	(Oct. 1959)				
1960 Feb./Mar./Apr. (c)	421	392	365		77	0·219	0·241	0·266
May/June/July (d)	291	259	229		27	0·106	0·121	0·140
	225	193	163					
	50	49	47	(May 1960)				
Aug./Sept./Oct. (e)	275	242	210		29	0·121	0·141	0·166
Nov./Dec./Jan. (f)	210	176	146		23	0·126	0·154	0·192
	159	127	99					
	43	41	40	(Oct. 1960)				
1961 Feb./Mar./Apr. (g)	202	168	139		43	0·260	0·326	0·415
May/June/July (h)	134	102	75		13	0·111	0·150	0·213
Aug. Sept./Oct. (i)	103	74	50		6	0·065	0·093	0·143
	83	57	35					
	526	507	488	(July 1961)				
Nov./Dec./Jan. (j)	609	564	523		93	0·180	0·199	0·219
1962 Feb./Mar./Apr. (k)	438	388	344		127	0·372	0·437	0·516
May/June/July (l)	260	210	168		49	0·227	0·293	0·387
Aug. Sept./Oct. (m)	178	132	93		14	0·089	0·123	0·182
Nov. Dec./Jan. (n)	140	98	63		13	0·106	0·157	0·259
1963 Feb./Mar./Apr. (o)	108	70	40		17	0·186	0·307	0·618
May/June/July (p)	77	43	18		9	0·135	0·259	0·769
						$\Sigma F'_v$ = 2·627	3·337	4·842
						F' = 0·657	0·834	1·211
						$X + F'$ = 1·26	1·53	2·01

N_0 Number of fish liberated, corrected for 30% tagging mortality.

n_t Number recaptured in initial period of duration t, corrected for an estimated 30% of recaptures not being reported.

N_v Calculated number of tagged fish at liberty at beginning of each time period v (= 0·25 years).

n_v Number of tagged fish recaptured in each quarterly period, v, corrected for an estimated 30% of recaptures not being reported.

X and X_v Assumed annual and quarterly values of instantaneous 'other loss' coefficient.

F'_v Calculated quarterly value of instantaneous fishing mortality coefficient.

Table 11. *Percentages of tagged cod recaptured by English, Scottish and Faroese vessels from English and Danish tagging experiments. Danish data from Strubberg* (1916, 1933) *and Tåning* (1940)

English experiments 1959–62 Recaptures to December 1963	Total recaptures	Percentage recaptured			
		England	Scotland	Faroe	Others
Plateau-tagged and recaptured Liberated 1959–61	768	17	69	12	2
Bank-tagged and recaptured Liberated 1962	155	54	25	17	4

Danish experiments 1909–37	Total recaptures	Percentage recaptured			
		England	Scotland	Faroe	Others
Plateau, 1909–13	1 571	8	1	91	0
Plateau, 1923–25	414	5	6	90	0
Plateau, 1927–37	189	33	44	20	3
Bank, 1910	87	45	11	44	0

recaptures being made by Faroese fishermen. Thus it would appear that the small cod tagged close inshore were not generally available to the British trawler fleet. In the later Danish experiments of 1927 and 1932 the fish tagged were larger in size and were tagged further from land. From these experiments 77% of the subsequent recaptures were reported by British vessels. However, the numbers of fish tagged and recaptured in these two years were too small for reasonable estimates of mortality rates to be calculated.

ASSESSMENT OF THE NATURAL AND FISHING MORTALITY RATES FOR THE FAROE PLATEAU STOCK FROM CATCH AND EFFORT DATA

To summarize from the preceding sections, it can be said that reasonable estimates have been obtained for the parameters of growth, L_∞ and K, and of total mortality, Z. Estimation of fishing and natural mortality coefficients was dependent on a somewhat arbitrary correction of errors in the results of tagging experiments. Thus it is appropriate to re-examine the data of fishing effort and catch per unit effort presented in Table 6 and Figure 4, with a view to narrowing down the range of values for coefficients of fishing and natural mortality for the Faroe Plateau stock.

Although the catch per unit effort against effort plot in Figure 4 is based on data for the whole of the Faroe region, it has been pointed out (above) that the decline in catch per unit effort has been similar on both Plateau and Bank (Figure 6). It has therefore been assumed that the relationship of catch per unit effort to effort for the Plateau stock is very similar to that shown in Figure 4.

As shown by Beverton (1964) it is possible to fit theoretical curves to the catch per unit effort against effort data. The data for the post-war period have been replotted in Figure 14a. In fitting the curves it has to be assumed that there is a proportional relationship between

fishing mortality and fishing effort, and a relationship between the ratio F M and fishing effort has been deduced. During the period 1959 60 61 the average fishing effort was about 115 units. The total mortality coefficient, Z, during these years was 1·1. Assuming values of the natural mortality coefficient, M, of 0·2 and 0·3, the corresponding values of F/M are $\frac{1{\cdot}1-0{\cdot}2}{0{\cdot}2} = 4{\cdot}5$ and $\frac{1{\cdot}1-0{\cdot}3}{0{\cdot}3} = 2{\cdot}7$, and therefore the following equivalence of effort and F/M has been adopted:

M = 0·2: One unit of F/M = 26 units of effort
M = 0·3: One unit of F/M = 43 units of effort.

Other parameters used were as follows: l_c (mean length at first capture) = 39 cm, L_∞ = 115 cm, K = 0·2; hence

$l_c/L_\infty = 0{\cdot}34$
M/K = 1·0 and 1·5.

The yield function tables of Beverton and Holt (1964) have been used to calculate the two theoretical curves of catch per unit effort against effort shown in Figure 14a. The corresponding curves of yield, calculated relative to the maximum in each case, are also shown. The curve for M = 0·3 gives a good fit to the data and indicates that the curve drawn by eye in Figure 4 has probably underestimated the abundance of the stock in the unfished state, and it appears more likely that in recent years the abundance has been reduced to about one tenth of that in the unexploited stock. Taking M = 0·3, the value of the fishing mortality coefficient for the period 1959–61 was F = 0·8. The curve of relative yield shows that at this level of fishing mortality the yield is not unduly depressed, falling only about 10% below the maximum. However, maximum yield could be obtained with only half the present amount of fishing, in which case the catch per unit effort would be almost two and a half times its value in recent years.

For a comparison of yield for different values of M, curves of yield in weight per recruit against fishing mortality have been calculated for the Plateau stock from the yield equation of Beverton and Holt (1957). These are shown in Figure 14b, for three values of M = 0·1, 0·2, and 0·3, using the following parameters:

W_∞ = 14,500 gm
K = 0·914
t_0 = −0·416
$t_r = t_c$ = 2.

From consideration of evidence from tagging experiments and from catch per unit effort data, it seems reasonable to conclude that likely limiting values of the natural mortality coefficient are 0·2 and 0·3. Corresponding values for the coefficient of fishing mortality in recent years are 0·9 and 0·8.

CONSERVATION

It is not intended here to deal in any detail with the question of conservation of cod at Faroe. This problem was considered by the North-Western Working Group in 1961 (ICES, 1962). With the very limited data at their disposal, and considering the Faroe fishery as a single stock unit, the Working Group provisionally concluded that the cod stock at Faroe was only moderately fished. The effect on landings of cod was assessed, in terms of immediate loss and long-term gain, of trawl codend mesh size increases from 75 mm to 110 mm and 130 mm. Values of the ratio F/(F + M) used were 0·3, 0·5 and 0·7. The conclusions reached were that the Scottish trawl fishery, catching the largest proportion of small fish, would

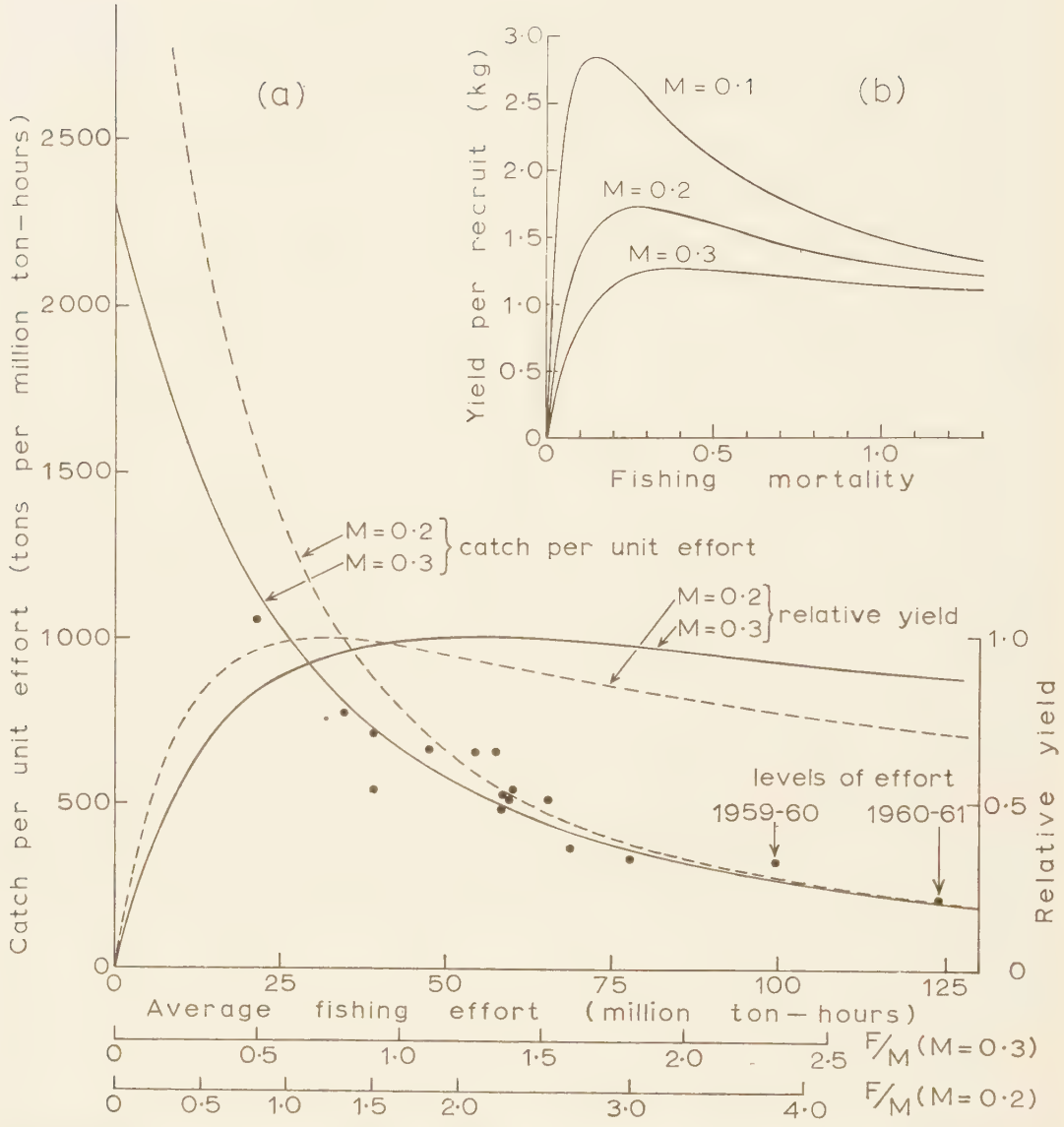

Fig. 14. (a) *Theoretical curves of catch per unit effort and relative yield fitted to a plot of catch per unit effort against average fishing effort for the post-war years.* (b) *Yield curves for the Faroe Plateau cod stock.*

experience the largest immediate loss but this would probably not exceed 8% with a mesh size increase to 130 mm. Total landings would show little long-term change with an increase to 110 mm and there would probably be a small long-term gain by increasing to 130 mm. The greatest long-term gain would be in the Faroese long-line catches and the least gain would be in the Scottish trawl landings.

The additional data which are now available show that the parameters used by the Working Group were reasonable ones. The figure of 3·4 used as a selection factor was based on results obtained in the North Sea and in the Arctic. Recent work (Jones, 1963) has confirmed the selection factor of 3·4 for cod at Faroe. Although fishing is fairly intensive, the upper figure taken by the Working Group of 0·7 for the ratio $F/(F + M)$ is unlikely to have been much exceeded in recent years. Thus the findings of the Working Group in respect of Faroe cod are unlikely to require revision in the light of recent data.

The cod at Faroe, unlike the haddock, are protected to some degree in that they do not recruit to the trawl fishery at an early age. Very few small fish are taken by trawlers and rejection at sea is correspondingly low. Research ships with covered codends also catch very few cod below 30 cm on either Plateau or Bank. The cod of Faroe Plateau presumably spend the early part of their life in the fjords and inshore waters, but if the Bank fish are a self-perpetuating stock and independent of the Plateau it is not known how the young fish distribute themselves so as to be unavailable to capture by trawls, unless they shoal in mid-water. Young haddock, on the other hand, are to be found in large numbers on grounds regularly fished by trawlers; there is often considerable rejection at sea, and the long-term gain from an increase in mesh size could be substantial. Thus as little change in the yield of cod is expected from mesh changes up to 130 mm, for any conservation measures involving a change in the minimum size of trawl codend meshes the haddock will be the more important species in determining the magnitude of such changes. However, a reduction of fishing effort on cod could be advantageous in giving a slightly increased yield and a substantial increase in catch per unit effort.

SUMMARY

THE demersal fishery at Faroe takes place on Faroe Plateau and Faroe Bank. The main participating nations, England, Scotland and the Faroe Islands, between them account for about 90% of the landings from the region. Cod is the most important commercial species, but in the post-war years haddock has been increasing in importance.

Evidence from tagging experiments indicates the existence of two self-contained cod stocks at Faroe, one on the Plateau and the other on Faroe Bank. The Bank stock has a particularly rapid growth rate. Growth parameters for both stocks have been calculated.

An examination of the fisheries statistics for Faroe showed that in post-war years the total catch of cod from the Faroe region fluctuated about a steady level. Fishing effort, on the other hand, has been steadily increasing and there has been a corresponding fall in catch per unit effort. The magnitude of the decline in stock density has been similar in both Plateau and Bank stocks.

Estimates of the instantaneous total mortality coefficients from age composition data over the period 1959–62 gave mean values of 1·07 for the Plateau stock and 1·27 for the Bank stock. Analysis of tagging experiments provided further information on mortality rates for the Plateau stock. If corrections are made on the assumptions that there was a 30% initial tagging mortality and that reporting of recaptured tags was 70% efficient, the calculated values of the instantaneous coefficients of fishing and natural mortality were 0·90 and 0·17. On fitting theoretical curves to catch per unit effort against effort data a good fit was obtained using a value of 0·3 for the natural mortality coefficient. It is concluded that the true value of the natural mortality coefficient of the Plateau stock falls within the limits 0·2 to 0·3, with corresponding limiting values for the fishing mortality coefficient in recent years of 0·9 and 0·8.

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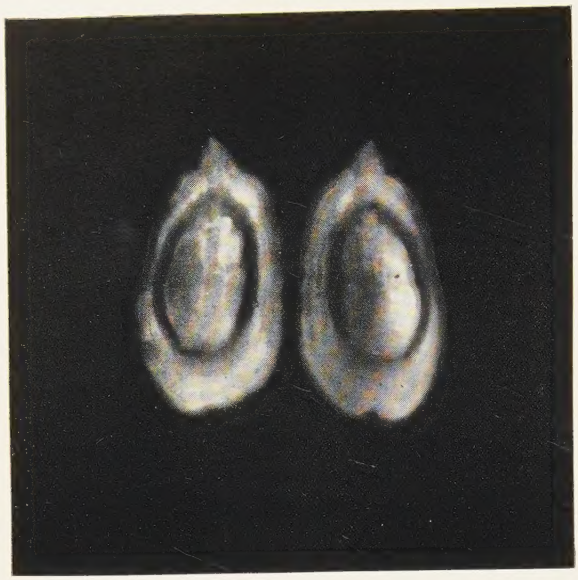
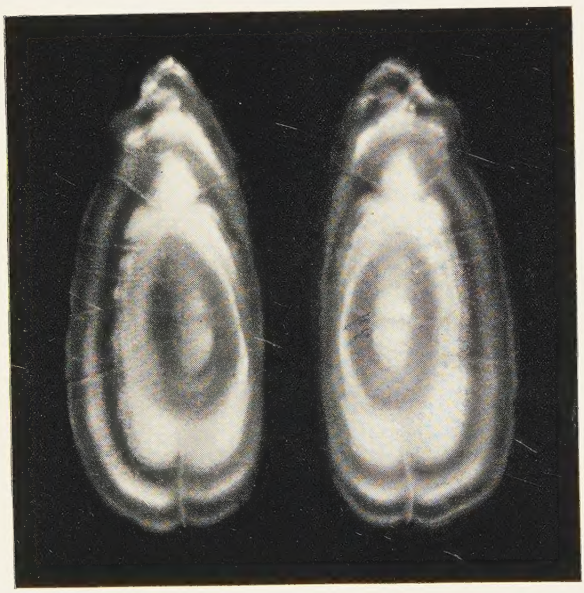
(a)



(b)

(c)



(d)

Photomicrographs of otoliths of three sand-eel species. Exposures by reflected light; otoliths immersed in xylene.

(a) A. marinus; *fish of* 15 *cm, caught on* 30 *June* 1961 *near Indefatigable Bank; two opaque zones* (*I-group*)*; otolith lengths* 2·4 *and* 2·5 *mm.*

(b) A. marinus; *fish of* 15 *cm, caught on* 30 *June* 1961 *near Indefatigable Bank; three opaque zones* (*II-group*)*; otolith lengths* 2·4 *mm.*

(c) A. lanceolatus; *fish of* 23 *cm, caught on* 31 *July* 1961 *near Texel lightship; four opaque zones* (*III-group*)*; otolith lengths* 4·1 *and* 4·2 *mm.*

(d) G. semisquamatus; *fish of* 17 *cm, caught on* 25 *May* 1961 *near the Southernmost Rough; ?two opaque zones and a third just beginning* (*?II-group*)*; otolith lengths* 2·6 *and* 2·7 *mm.*

PLATE 1